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1993-94-95 Kara Sea Field Experiments and Analysis

1995 Progress Report to ONR Arctic Nuclear Waste Assessment Program

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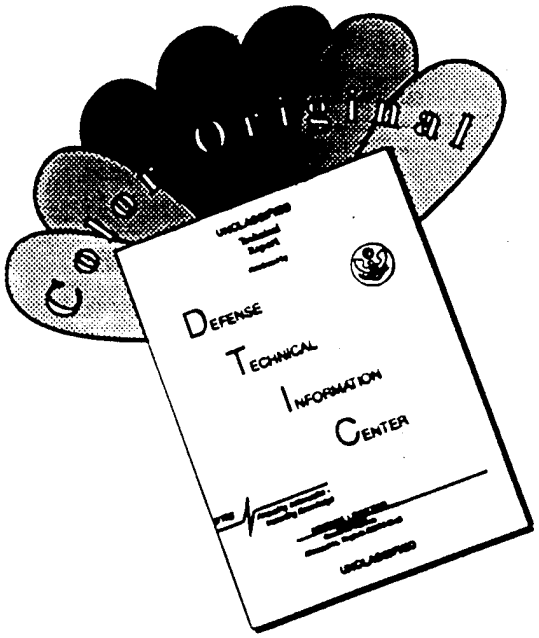

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13. ABSTRACT (*Maximum 200 words*)

This progress report covers field work and laboratory analysis efforts for quantifying the environmental threat of radioactive waste released in the Arctic seas adjacent to the former Soviet Union and for studying the various transport mechanisms by which this radioactivity could effect populations of the U.S. and other countries bordering the Arctic. We obtained water, sediment, biological samples and oceanographic data from several cruises to the Kara Sea and adjacent waters and conducted detailed laboratory analyses of the samples for radionuclides and physical-biological properties. In addition, we obtained water and sediment samples and conducted on-site low-level radionuclide analysis on the Angara/Yenisey River system which drains a major part of the Siberian industrial heartland and empties into the Kara Sea. We report on radionuclide concentrations, on radionuclide transport and scrubbing by sediments, on adsorption by suspended particles, on transport by surface and benthic boundary layer currents, on the effects of benthic and demersal organisms, on studies of long-term monitoring in the Arctic and on an interlaboratory calibration for radionuclide analysis.

14. SUBJECT TERMS

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Radioactive waste
Kara Sea
Long-term monitoring
Angara River
Yenisey River
Radionuclide concentrations
Inter-laboratory calibration
Physical transport processes
Biological transport processes

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1993-94-95 KARA SEA FIELD EXPERIMENTS AND ANALYSIS 1995 PROGRESS REPORT TO ONR ARCTIC NUCLEAR WASTE ASSESSMENT PROGRAM

1. Overview: 1993-94-95 Field Experiments and Analysis

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I. Narrative Documentation

A. Long term goals

Assessment and modeling of the environmental threat from the introduction of radionuclides into the Arctic depend on extensive data obtained by field expeditions and analysis of field samples in order to characterize and quantify the current contamination and potential threat for future releases. Results from the 1993 and 1994 cruises sponsored by ONR and others in the Arctic have helped to define the threat due to dumping by the former Soviet Union in the western Kara Sea and adjacent fjords on the eastern shore of Novaya Zemlya. This dumping has been reported in the "White book" of Yablokov to consist of thousands of containers of solid radioactive waste as well as fueled and unfueled reactors from nuclear powered vessels.

For the last two and a half years NRL has conducted a broadly diversified program in support of the ONR ANWAP effort. One aspect of the NRL work has aimed at obtaining the necessary information through field work and laboratory analysis for quantifying the environmental threat of radioactive releases in the Arctic seas adjacent to the former Soviet Union and for studying the various transport mechanisms by which this radioactivity could effect United

Manuscript approved December 14, 1995.

States populations. We have played a leading role in three major cruises to the Kara sea in each year from 1993 through 1995 and participated in an additional cruise to the St. Anna trough in 1994. During these cruises careful sampling was conducted for water and sediment which were returned for detailed analysis in the laboratory for radionuclides and physical-biological properties. In addition, we played a leading role in planning and conducting an expedition to the Angara/Yenisey river system in 1995 to investigate the land-based sources of pollution in this major river system which empties into the Kara sea. We obtained water and sediment samples and conducted low-level radionuclide analysis in a field laboratory in Siberia for near real time results.

B. Objectives of this effort

This effort has had several objectives each of which is covered in more detail in the separate reports which follow. A brief statement of the objectives for each report is given below.

- Define the radioactivity source term both in the Kara sea and in land based sources along the major river systems which empty into the Kara sea by careful sampling followed by low-level radionuclide analysis. (see Phillips[1,2]], August[1], and King[1,2])

- Conduct an interlaboratory comparison for radionuclide analysis using NIST standard samples. (see August[2])

- Assess the role of sediments in the transport of radionuclides and model the scrubbing potential of sediments. (see Burkett)

- Assess the importance of surface layer boundary flow and benthic boundary currents in the Kara sea on the distribution and fate of radionuclides. (see King[2])

- Conduct a workshop on radionuclide monitoring in the Arctic and produce improved and innovative methods for monitoring radionuclide levels in the Arctic. (see King[3])

- Determine the potential for offshore and nearshore transport of radionuclides in the Kara sea by adsorption to suspended particles. (see Lavoie)

- Assess the effects of nuclear pollutant impacts on benthic (bottom-dwelling) and demersal (near-bottom) organisms and their processes affecting the biogeochemistry of sea floor sediments. (see Briggs)

References

The following references give the first author and title of the individual reports which follow:

2. ^{137}Cs in St. Anna Trough Sediment

Principal Investigators:	R.A. August[1] G.W. Phillips[1] S.E. King[1] P.J. Burkett[2] G.I. Ivanov[3] Yu.K. Bordukov[3] P.I. Krinitski[3] A.V. Nescheretov[3] A.D. Krasnyuk[3]
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I. Narrative Documentation

A. Long Term Goals

The widely publicized report (Yablokov-1993) of the dumping of nuclear materials by the former Soviet Union in the Kara Sea region caused widespread concern which resulted in the U.S. Office of Naval Research (ONR) program to characterize the problem. Most of the money has been spent on expeditions to sample water, sediment and biota for possible radionuclear contamination. NRL has been deeply involved in this effort, especially in the area of sediment analysis. Over the last few years we have analyzed numerous sediment samples from this region as part of the greater effort to map out this area experimentally. The current study extends our work to the northern part of this region.

B. Objectives of this effort

The objective of this effort was to collect sediment samples from the St. Anna trough region to be brought back to the laboratory for radionuclear analysis. We were looking specifically for indications of anthropogenic radionuclides above the levels that can be explained as being due to global fallout. The St. Anna trough is the most direct outlet from the Kara Sea into the Central Arctic basin. Any elevated levels of radionuclides escaping from this region into the Arctic basin should leave evidence of its passage in the sediment record of the St. Anna trough. We are therefore looking to the sediment record to provide an indication as to whether there has been any escape of anthropogenic radionuclides form the Kara Sea via this pathway. This will aid in the assessment of this region as a potential source of radionuclear pollution beyond the local Kara Sea region.

C. Approach

P.J. Burkett of the Naval Research Laboratory (NRL) participated in the 1994 cruise of the Russian ship "Professor Logachev." With the aid of her Russian hosts, she collected sediment box cores at 21 different stations in the St. Anna trough region between August 11 and September 7, 1994. The locations, dates and depths of these samples are shown in Table 2.1. Each box core was sub-sampled with a three inch diameter coring tube. One centimeter slices were taken from this tube and saved in individual plastic bags. These one centimeter samples were taken from 0 to 10, 13 to 14, 16 to 17, and 19 to 20 centimeters. These samples were kept frozen until their return to NRL. At NRL, they were freeze dried to remove the water. The dry weight of the individual samples ranged from 10 to 40 grams. Each sample was then individually analyzed in the NRL Low-Background High-Resolution Gamma Ray Detection System.

The NRL Low-Background High-Resolution Gamma Ray Detection System consists of four liquid nitrogen cooled, high purity Ge detectors in individual lead caves. Each cave has a minimum wall thickness of 8 inches of lead. The detectors are oriented in the vertical position with the cooling dewar on top and connected by insulated hoses to a semi-automated fill system. During analysis, a sediment sample is held flat against the detector face by a plastic cup fitted over the detector head. Access to the detector heads is via rolling lead doors. Pre-amp power and detector bias high voltage are applied by power supplies residing on top of the lead caves. The warm-up signals from the detectors are sent to the high voltage power supplies to activate an automatic shut-off circuit that prevents damage in the case of accidental warm-ups.

The pre-amp signals from each detector are sent to computer-card resident amplifiers and multi-channel analyzers (ADCs). The computers are 66 MHZ 486 PCS. The acquisition software is by Aptec Nuclear Company. The data are collected in 4096 channel spectra for an average collection time of 24 hours, though this can vary widely depending on signal strength and desired statistical accuracy. The average energy resolution obtained was 2 keV at the 662 MeV ^{137}Cs line, with a energy spectrum ranging from 40 keV to 3 MeV. The background counting rate inside the caves was less than one count per second. The average gamma ray detection efficiency was 2% for the 662 MeV ^{137}Cs line. The efficiency calibrations were done using NIST standard sediment

samples and specifically designed calibration standards manufactured by Northern Scientific Company for this detector system. To obtain a sufficiently sensitive efficiency calibration, the detectors had to have calibrations that were dependent on both gamma-ray energy and sample mass.

A background spectrum was taken for each cave without a sediment sample being present. Analysis for individual gamma ray lines in a sediment sample spectrum was done by first subtracting the live time corrected background counts for that cave from the spectrum. The activity for each gamma ray line was then quoted in Bq/kg dry weight for the isotope which was responsible for that gamma ray line. In order to be consistent, all activities were decay corrected to a collection date of August 15, 1994.

D. Accomplishments and E. Results

We were looking for both natural and anthropogenic radionuclides such as ^{137}Cs, ^{208}Tl, ^{214}Bi, and ^{228}Ac. The 2 keV energy resolution of the NRL Low-Background High-Resolution Gamma Ray Detection System allowed us to sensitively survey our spectra for the presence of any unusual isotopes that might indicate an anthropogenic source other than fallout. None of the spectra analyzed give any such indication. All of the surface (0 to 1 centimeter) samples have been analyzed. Of these, the only anthropogenic radionuclide to give a consistently measurable signal was ^{137}Cs. The results are tabulated in Table 2.2 in units of Bq/kg dry weight. The quoted error represent two standard deviations. The results are shown graphically in Figure 2.1. These values are all very low and easily within the range of what one could expect from global fallout.

We also analyzed seven complete cores. Again, only ^{137}Cs gives a consistently measurable anthropogenic signal. The results for the complete cores are quoted as column burdens in units of Bq/m^2. These results are tabulated in Table 2.3. The quoted error represent two standard deviations. The results are shown graphically in Figure 2.2. These values are again very low and easily within the range of what one could expect from global fallout.

F. Impact for science or systems applications

All of the ONR supported cruises have allowed access to an area of the world that was previously off-limits. By enlisting the help of our Russian colleagues, we not only obtain valuable scientific assistance, but also support Russian science during a critical juncture in its history.

G. Transitions expected

None.

F. Relationship to other projects

This data adds to the overall picture being formed of the region by ONR sponsored researchers. In particular, this data merges with previous data to extend the studied region

northward, and to begin answering the question of possible pathways from the Kara Sea to other regions.

I. Application to the Arctic Radioactive Waste Assessment problem

As stated previously, the St. Anna Trough is the most direct pathway to the Central Arctic Basin. All our measurements of these sediments show very low ^{137}Cs values that are easily explainable in terms of global fallout. Additionally, there were no indications in our data for elevated levels of any other possible anthropogenic radionuclides. Therefore, any radionuclear contamination that may have been transported from the Kara Sea area through the St. Anna trough must have done so without leaving significant traces in the sediment record. Since the possibility of this happening seems remote, we conclude that the absence of elevated levels of radionuclides in the sediment record indicates that there has been no transport of radionuclear pollution from the Kara Sea region into the central Arctic basin via the St. Anna trough.

II. Statistical Information

A. List of publications

R.A. August, G.W. Phillips, S.E. King, P.J. Burkett, G.I. Ivanov, Yu.K. Bordukov, P.I. Krinitski, A.V. Nescheretov and A.D. Krasnyuk, "^{137}Cs in St. Anna Trough Sediment," submitted for publication in "Contamination in the Arctic," a special issue of The Marine Pollution Bulletin

B. Number of graduate students

None.

C. Patents

None.

D. Presentations

1. R.A. August presented at the Arctic Nuclear Wastes Assessment Workshop, Woods Hole Oceanographic Institute, Woods Hole, MA, 1-4 May 1995.

2. R.A. August presented at the International Conference on Environmental Radioactivity in the Arctic, Oslo, Norway, August 20-25, 1995.

E. Committed service

None.

F. Awards

None.

G. Russian participation
(% time and estimated contribution from ONR ANWAP)

1. Research Cruise: ??% ($?????)

2. Radionuclide Analysis: 0% ($0)

3. Interpretation of results and publications: 0% ($0)

References

Yablokov, A.V., Karasev, V.K., Rumyantsev, V.M., Kokeyev, M.Ye., Petrov, O.I., Lysysov, V.N., Yemelyanenkov, A.F. and Rubtsov, P.M. (1993). Facts and problems related to radioactive waste disposal in seas adjacent to the territory of the Russian Federation. Moscow, Office of the President of the Russian Federation, 72 p.

Table 2.1. Station Log

STATIONS IN ST. ANNA TROUGH					
station	*longtitude*	*latitude*	*date*	*time*	*depth*
	(degrees)	*(degrees)*		*(GMT)*	*(meters)*
1	67.167	81.175	8/11/94	14:20	538
2	66.618	80.668	8/11/94	22:38	596
6	69.990	80.682	8/12/94	20:17	594
7	67.655	81.998	8/13/94	14:14	638
11	70.082	81.482	8/14/94	12:51	——
16	77.502	81.183	8/15/94	11:13	110
18	75.659	80.594	8/15/94	21:51	163
20	71.814	80.655	8/16/94	7:39	577
24	73.117	80.007	8/17/94	16:22	457
25	74.415	79.991	8/17/94	20:59	224
29	70.003	80.019	8/19/94	1:34	605
33	69.715	79.395	8/18/94	3:03	535
38	65.570	79.353	8/21/94	19:39	440
40	62.724	79.333	8/22/94	7:37	191
49	65.399	80.662	8/24/94	18:39	140
56	75.551	77.844	8/28/94	17:01	346
60	70.063	76.995	8/29/94	18:58	572
67	67.487	78.410	9/1/94	9:36	400
70	63.665	78.207	9/1/94	22:24	378
71	42.292	80.599	9/7/94	5:42	411
72	42.076	80.214	9/7/94	11:00	378

Table 2.2. Surface ^{137}Cs Results

^{137}Cs 0 to 1 cm Results		
station	*concentration*	*error*
	(Bq/kg dry weight)	*(2 sigma)*
1	5.17	2.90
2	5.83	3.03
6	6.35	2.40
7	4.54	3.64
11	3.82	2.61
16	4.92	1.17
18	7.02	1.69
20	4.53	3.75
24	8.31	1.51
25	6.00	1.36
29	5.79	1.85
33	3.93	1.22
38	2.05	1.25
40	4.12	0.652
49	7.57	0.853
56	7.31	1.01
60	11.20	3.02
67	5.82	1.68
70	6.11	1.58
71	8.21	1.96
72	6.60	0.886

Table 2.3. ^{137}Cs Column Burdens

^{137}Cs Integrated Column Burdens		
station	*column burden*	*error*
	(Bq/m^2)	*(2 sigma)*
11	112.	36.7
38	71.8	23.6
40	83.0	25.1
56	122.	22.8
60	317.	43.1
67	146.	23.4
72	122.	15.3

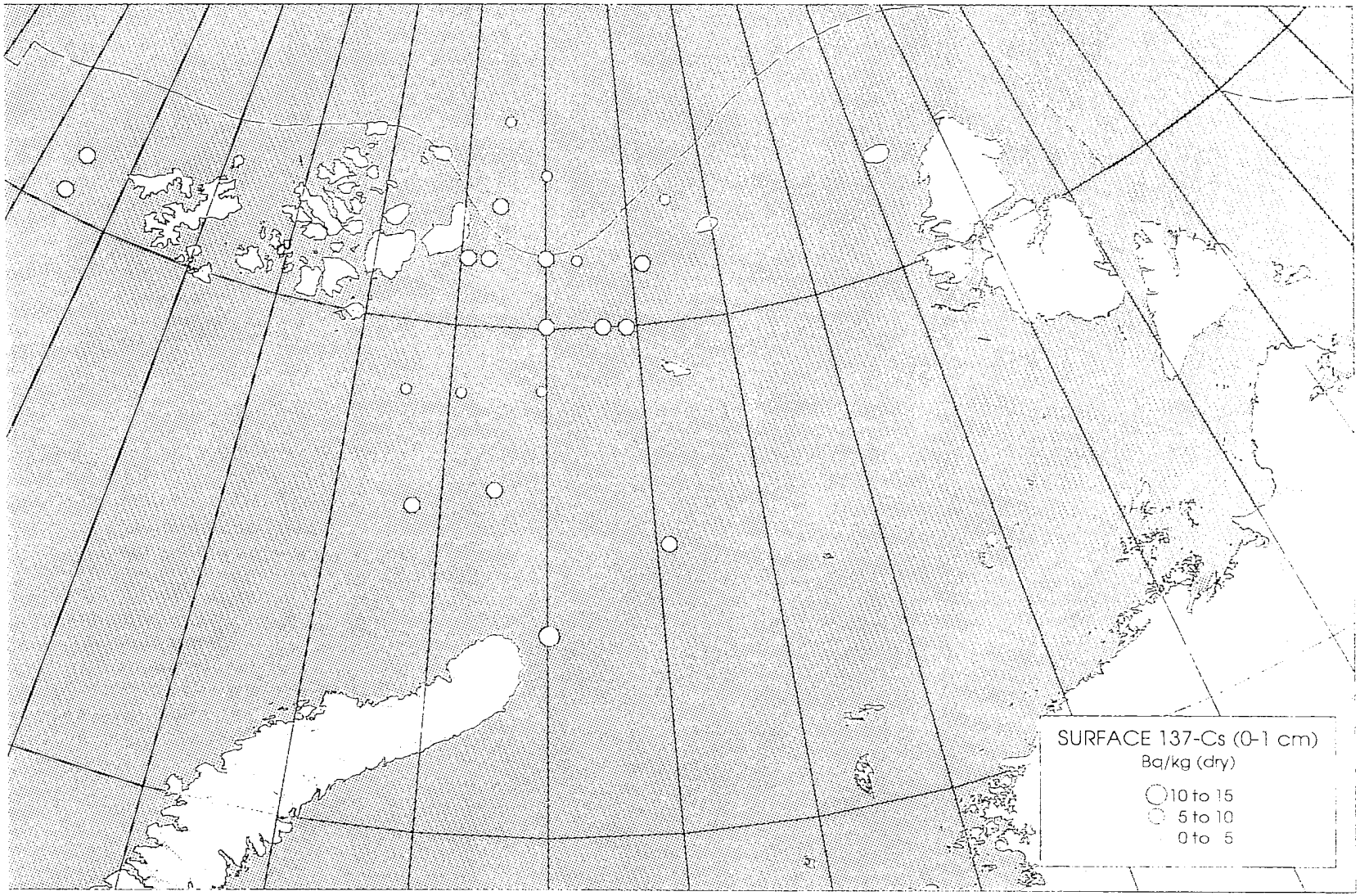

Figure 2.1. Surface (0 to 1 centimeter) ^{137}Cs from Table 2.2.

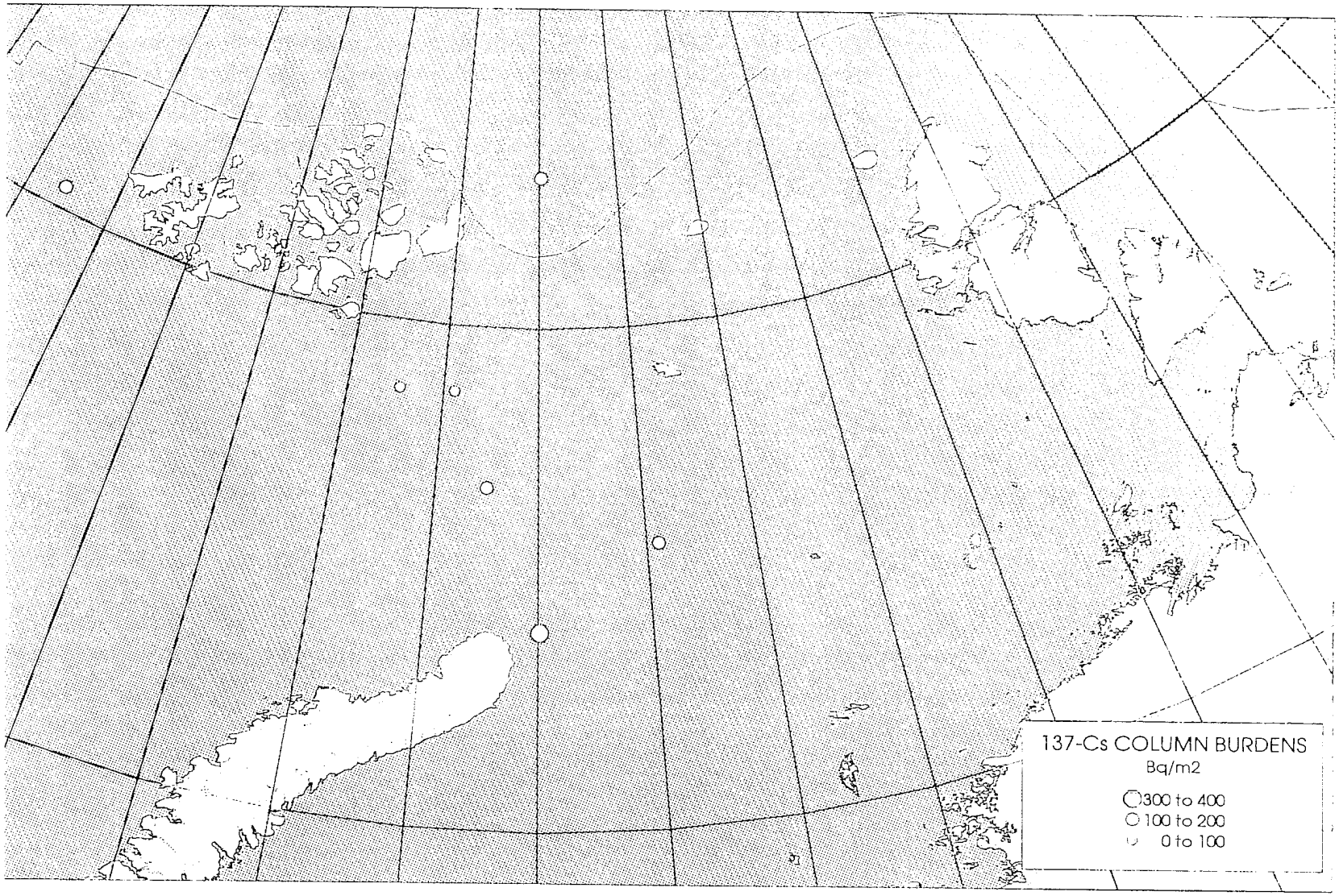

Figure 2.2. Integrated ^{137}Cs column burdens from Table 3.3.

3. Gamma Ray Intercalibration

Principal Investigators:	R.A. August G.W. Phillips S.E. King
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I. Narrative Documentation

A. Long Term Goals

ANWAP has funded a plethora of scientific measurements in the course of its program. Many labs are measuring the same physical parameters. In order to insure quality control, ONR needs to have a program in place to keep it informed on how different labs compare when measuring the same physical parameters. This effort was confined to gamma ray measurements of sediment, but in the future there is a broader effort needed.

B. Objectives of this effort

The objective of this effort was to send samples of a sediment standard to all labs participating in ANWAP sponsored gamma ray measurements of sea sediments. The labs were instructed to measure the samples for ^{137}Cs content by their usual methods, then return the results to NRL for intercomparison. The test is blind, so no lab (except NRL) has access to the other lab's numbers. These results serve to give ONR a sense of how consistently these measurements are being made from lab to lab. It's important to note that this is not meant to be a full blown quality control program, but merely an intercalibration.

C. Approach

The material chosen was a sample from the National Institute of Standards and Technology in Gaithersburg, MD (NIST). The sample was labeled by NIST as "Irish Sea Sediment." The sample was collected, homogenized, and measured in the mid-1980's. There were, however, some problems with its homogeneity and it was never certified as a standard. For our purposes, the homogeneity problems were not considered severe enough to eliminate this substance as useful. On the other hand, it was of the same nature as the materials everyone was measuring, its source in the Irish Sea ensured measurably high levels of ^{137}Cs, it was available in large enough quantities, and it wasn't already being

used as a calibration standard by the labs being intercompared (though some had seen it in previous years). It therefore seemed the overall best material available.

Eleven different labs were sent samples, but only seven ended up sending results. In alphabetical order, the seven are:

LAB: Argonne National Laboratory
CONTACT: Kent Orlandini
ADDRESS: Argonne National Laboratory
Bldg.. 203, E166, Environmental Research Division
Argonne, IL 60439

LAB: Bedford Institute
CONTACT: John Smith
ADDRESS: Dept. Of Fisheries & Oceans
Bedford Inst. Box 1006
Dartsmouth Nova Scotia, CANADA B2Y 4A2

LAB: Environmental Measurements Laboratory
CONTACT: Thomas Beasley
ADDRESS: U.S. Department of Energy Environmental Measurements Laboratory
376 Hudson Street
New York, NY 10014-3621

LAB: Environmental Protection Agency
CONTACT: Colleen F. Petullo
ADDRESS: U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
P.O. Box 98517
Las Vegas, Nevada 89193-8517

LAB: Los Alamos National Laboratory
CONTACT: Wes Efurd
ADDRESS: Los Alamos National Laboratory
P.O. Box 1663 Mail Stop J514
Los Alamos, NM 87545

LAB: Oak Ridge National Laboratory
CONTACT: Lee W. Cooper
ADDRESS: Environmental Sciences Division
MS 6038, Bldg.. 1505 - Oak Ridge National Lab
P.O. Box 2008
Oak Ridge, TN 37831

LAB: Naval Research Laboratory
CONTACT: Robert A. August Jr.
ADDRESS Code 6616, U.S. Naval Research Laboratory
4555 Overlook Avenue SW
Washington, DC 20375

Not all of these labs received funding directly from ANWAP, but instead performed the analysis for organizations that did.

In order to avoid any reluctance to participate, it was decided to not report the results for each lab by name. Instead, each lab was randomly assigned a number between one and seven. Results here are reported only by lab number. The identification of labs with numbers is being sent separately to ONR and is not for general distribution.

D. Accomplishments and E. Results

The results of the measurements made by the individual labs are presented in Table 1. Four labs made multiple measurements, so a statistical mean was calculated to represent their results. All quoted errors are two sigma results, as is typical in the field of environmental radionuclear measurements. All results are quoted in units of Bq/kg regardless of the units in which they were reported. The decay dates are those reported by the contact for each lab. The sample tested column gives the sample ID reported. In some cases this was the number on the NIST label, in others it was an arbitrary number assigned by the lab.

A mean was calculated of all individual measurements and their quoted errors. Additionally, a standard deviation was calculated for the entire set of measurements. Both these calculations were performed after first dating all measurements to 6/1/94. A quick inspection of Table 1 shows that the lab 7 results are anomalously large; therefore, its results were left out of all statistical calculations. The results of the calculations are shown at the bottom of Table 1. The mean quoted error and the standard deviation of the distribution are in close agreement, with the latter being slightly larger. The close agreement between the two indicates that any systematic error in the measurements is small, and that the statistical error does a reasonable job of accounting for the spread in the data.

Performing statistics on the individual measurements has the effect of giving greater weight to those labs making numerous measurements. To eliminate this bias, the mean results for each lab were used to form a new distribution where each lab has only one entry. This distribution and its associated statistics are shown in Table 2. Even though this is a much smaller data set, the results are essentially the same as those from Table 1 and the same conclusions apply. It can therefore be stated that—with the exception of lab 7—the individual labs are in close agreement concerning their reporting of absolute values of ^{137}Cs in sea sediment.

F. Impact for science or systems applications

The close agreement means that ONR can now compare reported results from the various reporting labs with confidence. It also means the individual labs now have a benchmark of how they compare with others.

G. Transitions expected

This effort needs to be expanded to a full quality control program for all ANWAP investigators.

F. Relationship to other projects

The confidence with which data can be compared effects all the research efforts being conducted. The present effort, however, is limited in scope to those labs conducting gamma ray analysis of sediments containing isotopes emitting gamma rays in the several-hundred keV energy range.

I. Application to the Arctic Radioactive Waste Assessment problem

A full quality control program for all physical parameters being measured by the various labs receiving ANWAP funding seems appropriate if ONR is going to draw overall conclusions from the data it receives. Whether this should be handled by one lab, by expert labs for each physical parameter, or by using programs already in place for other missions—like DOE's program at its Environmental Measurements Laboratory—is a subject worthy of investigation. Given the number of expert labs involved in ANWAP, it should be possible to set up a quality control program in a cost effective and timely manner.

II. Statistical Information

A. List of publications

None.

B. Number of graduate students

None.

C. Patents

None.

D. Presentations

None.

E. Committed service

None.

F. Awards

None.

G. Russian participation

None.

References

Laboratory identification being sent to ONR under separate cover. Not for general dissemination.

Table 3.1. Individual Results on Irish Sea Samples

INDIVIDUAL LABORATORY RESULTS					
laboratory	*sample tested*	*detector*	*decay date*	*^{137}Cs*	*quoted error*
				(Bq/kg)	*(Bq/kg)*
LAB_01	1	1190	1/1/94	10.9	1.1
	1	2663	1/1/94	10.9	0.5
	1	6037	1/1/94	11.1	0.4
	1	1164	1/1/94	11.3	0.5
	1	30816A	1/1/94	10.6	0.4
	1	2011	1/1/94	11.6	0.6
	1	23P84Xb	1/1/94	12.1	0.7
LAB_01 MEAN:				**11.2**	**0.6**
LAB_02	1	A2	6/1/94	11.4	0.8
	1	A4	6/1/94	10.0	0.7
	1	B2	6/1/94	9.7	0.7
	2	A2	6/1/94	10.1	0.7
	2	A4	6/1/94	10.0	0.7
	2	B2	6/1/94	9.7	0.7
	4	A2	6/1/94	10.9	0.8
	4	A4	6/1/94	11.1	0.8
	4	B2	6/1/94	10.7	0.7
LAB_02 MEAN:				**10.4**	**0.7**
LAB_03	1	—	6/1/94	12.9	0.8
LAB_04	1	—	3/1/95	13.8	1.0
LAB_05	1	—	4/17/95	12.1	0.2
LAB_06	501	1	6/1/94	13.5	0.7
	501	2	6/1/94	13.3	0.9
	501	3	6/1/94	13.1	0.8
	501	4	6/1/94	12.6	0.5
	185	1	6/1/94	13.0	1.1
	185	2	6/1/94	12.9	0.8
	185	3	6/1/94	11.3	0.6
	185	4	6/1/94	12.7	0.8
LAB_06 MEAN:				**12.8**	**0.8**
LAB_07	400	—	3/20/95	186	20
	401	—	3/20/95	179	19
LAB_07 MEAN:				**183**	**20**
Mean of all individual measurements [dated to 6/1/94]:				**11.6**	**0.7**
Standard deviation of the distribution [dated to 6/1/94]:					**1.3**
*** NOTE: LAB_07 excluded from the statistical calculations ***					

Table 3.2. Summary Results on Irish Sea Samples

SUMMARY RESULTS DATED TO 6/1/94		
laboratory	mean ^{137}Cs	quoted error
	(Bq/kg)	*(Bq/kg)*
LAB_01	11.1	0.6
LAB_02	10.4	0.7
LAB_03	12.9	0.8
LAB_04	14.0	1.0
LAB_05	12.4	0.2
LAB_06	12.8	0.8
LAB_07	186.0	20.0
MEAN:	**12.3**	**0.7**
*** NOTE: LAB_07 excluded from the statistical calculations ***		

4. Benthic Boundary Layer Processes Affecting Pathways of Radioactive Wastes in Shallow Arctic Seas

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Progress on this project is reported in a classified addendum.

5. Physical and Geotechnical Properties of Fine Grain Kara Sea Sediments

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I. Narrative Documentation

A. Long-term goals

The long term goal is to assess the role of sediments in transport of radionuclides and model scrubbing potential of sediments. Fine grained sediments actively scrub radioactive isotopes from solution and retain them on surfaces of particles. As a result, dispersion of radioactive waste from a localized source can be virtually hindered, retarded, or immobilized depending on the particular type of sediment. This scrubbing potential is dependent on mineralogy, microstructure, and properties of the sediment ,and the specific isotopes involved. Redox potentials and retention by organisms can significantly affect isotope adsorption/desorption onto sediment/clay particles. Also significant and not well understood is the role of organics and clay/organic interactions in the depositional and diagenetic processes and in the behavior of fine-grained sediments. The basis of model development is the use of the distribution coefficient (K_D) for specific radioactive species as affected by mineralogy, grain size, and geochemistry of the sediment. The rate of movement and transport pathways of radionuclides into the environment are controlled by the combined effects of the scrubbing potential and movement of the pore water.

B. Objectives of this effort

In order to assess the role of sediments in the transport of radionuclides, characterization of physical properties of the sediment must be determined. Our analyses focus on physical and geotechnical properties of selected sediments, in order to understand depositional and post-depositional processes, including transport effects. Laboratory analyses include: porosity, water content, bulk density, grain density, grain size, salinity, quantitative mineralogy, and permeabilities. Data from core analyses provide input parameters for scrubbing potential models and can be integrated with kinetic models from water column and biota. Better representation of this Arctic sub-environment essential for a good statistical data base and real-world models.

C. Approach

Subcores, collected from box cores and carefully sealed, were brought back to the NRL laboratory for analyses. The number of subcores (up to three) successfully collected down hole from the box core in the field depended on environmental factors and quality of sediment. Geotechnical properties (compressibility, coefficient of consolidation, and hydraulic conductivity), in addition to physical properties, where performed using the top few centimeters of the cores. Water content and vane shear strength were determined from the top and bottom of the subsample cores when enough sediment was present. All analyses were performed according to standard protocol including ASTM techniques.

D. Accomplishments

These laboratory analyses will provide critical input for kinetic modeling of scrubbing potentials and understanding the role of sediments in transporting contaminants.

E. Results

In general, the physical properties indicate fine-scale heterogeneity associated with varying subenvironments which are influenced by rivers. Figure 5.1 shows the location of environmental stations within the Kara Sea which were box cored. Details of sediment descriptions can be found in Young, et al. Stations 9, 9D, 10, and 11 are located proximal and significantly influenced by fresh water input. Figure 5.2 shows the shear strength of sediments as determined by a vane shear device. Note the increase of shear strength for river-influenced sediments relative to deeper water sediments. Figures 5.3 and 5.4 indicate water content of the sediments. Analyses of stations 9D and 10 indicate higher water contents. Station 9 contains a high clay mineral content; station 10 is sand-dominated. A closer look at clay mineralogy and grain size is warranted to completely understand water content/shear strength relationship. From the stations in which only one cored subsample was able to be collected, water content is below 50%. The top and bottom labels indicate the location of the analyses of the core. The slight increase of bottom water content indicates pore fluid drainage and accumulation. An average of top and bottom values would better represent water content of each subcore. Figure 5.5 graphs salinity of pore fluid and water content of all samples. The salinity scale is exaggerated but does indicate the influence of fresh water input from rivers.

The summary Table 5.1 lists the results of detailed analyses of the top centimeters of each cored subsample. Bulk density and compressibility increase with increased depth which correlates to decreased porosity and hydraulic conductivity. Interesting, within the depth of the box core, the coefficient of consolidation indicates little variation.. Figure 5.6 shows grain size distribution consisting of the percentages of sand, silt, and clay. Note station 10 is the only sand-dominated station and is supported with lower specific gravity and porosity and higher bulk density values. Figure 5.7 shows pie diagrams of percentages of clay minerals, smectite chlorite, kaolinite, and illite of the clay size fraction ($<3.9\ \mu m$). All samples contained all the major clay minerals, and all were dominated by illite.

F. Impact for science or systems

The first phase for development of the model for scrubbing potential is completed. Characterization of Arctic subenvironments is necessary and will allow resolution of the dynamic properties of sediments for fine-tuning models.

G. Transition expected

We want to continue analyses of sediment cores and use additional parameters as inputs to models currently being developed. Microfabric of sediments can be correlated to diffusion, permeability, redox/pH layers, bioturbation, and the role of organics. Microfabric can be define as the 3D arrangement and orientation of clay-sized particles resolvable using analytical electron microscopy. Microfabric analyses of Arctic fine grain sediments is in progress. NRL Code 7400 is enhancing capabilities by acquiring a 300 kV Transmission Electron Microscope with an Environmental Cell, EDS, PEELS, and CCD systems for state-of-the-art analytical and image analyses.

H. Relationships to other projects

Seafloor Geosciences Division (Code 7430) of NRL is currently (and historically) investigating physical properties, including sediment microfabric, of many environments of deposition. Our analyses supports efforts including sediment transport/sediment dynamics, sediment/ water interface dynamics, and biogeochemical interactions affecting formation and diagenesis of sediments including marine snow.

I. Application to the Arctic Radioactive Waste Assessment problem

Sediment analyses is vital to our gaining an understanding of the significance of sediments relative to their role in radionuclide transport

II. Statistical Information

A. List of publications

none

B. Number of graduate students

none

C. Patents

none

D. Presentation

Provided input for presenter, Dr. Dave Young, NRLSSC Code 7331

E. Committed service

none

F. Awards

none

G. Russian participation

In July-Aug 1994, I participated on a geologic Russian cruise aboard the RV *Professor Logachev* surveying and coring Saint Anna Trough located between the Barents Sea and Kara Sea. I systematically subsampled sediment subcores from box cores for detailed radionuclide analyses by Drs. Gary Phillips and Steve King, NRLDC. I also collected subcores for analyses of selected physical properties and total organic carbon.

Table 5.1. Summary Results

SAMPLE	9C1	9D	10C1	11	14C1	16C1
Specific Gravity	2.76	2.73	2.69	2.74	2.75	2.82
% finer than .074 mm	89	76	23	92	92	94
% finer than .002 mm	54.00	46.00	12.00	34	56	50
%Sand	11	24	77	8	8	6
%Silt	35	30	11	58	36	44
%Clay	54	46	12	34	56	50
Initial water content in %	124	87	31	104	164	155
Initial void ratio [e=Gw]	3.43	2.37	0.83	2.86	4.52	4.36
Initial porosity [n=e/(1+e)]	0.77	0.70	0.45	0.74	0.82	0.81
Initial bulk density[=(G+Se)/(1+e)]	1.40	1.51	1.93	1.45	1.32	1.34
Liquid Limit	120	91	NP	83	126	133
Plastic Limit	36	28	NP	42	42	38
Plasticity Index	84	63	NP	41	84	95
Activity	1.56	1.37	NA	1.21	1.50	1.90
Liquidity Index	1.05	0.93	NA	1.52	1.46	1.23
Compression Index	0.97	0.85	0.35	0.87	1.2	1.2
Rebound Index	0.19			0.07	0.15	
Preconsolidation Stress, kPa	3.0	16.0	40.0	3.0	4.0	3.5
Bulk Density, gm/cc						
Depth 0.01m	1.39	1.40	1.91	1.44	1.32	1.34
Depth 0.1 m	1.39	1.40	1.91	1.45	1.32	1.34
Depth 1m	1.41	1.40	1.92	1.50	1.36	1.37
Depth 10 m	1.52	1.47	1.99	1.66	1.48	1.48
Depth 30m	1.65	1.55	2.50	1.90	1.57	1.61
Porosity						
Depth 0.01m	0.78	0.77	0.46	0.75	0.82	0.81
Depth 0.1 m	0.78	0.77	0.46	0.74	0.82	0.81
Depth 1m	0.77	0.77	0.46	0.71	0.79	0.80
Depth 10 m	0.70	0.73	0.41	0.62	0.73	0.74
Depth 30m	0.63	0.68	0.11	0.48	0.67	0.67
Hydraulic Conductivity, cm/s						
Seafloor interface-estimated	3.50E-07	3.5E-07	1.3E-06	2.0E-07	5.0E-07	6.8E-07
Depth 0.01m-measured						6.8E-07
Depth 0.1 m	3.5E-07	3.5E-07	1.3E-06	1.8E-07	5.0E-07	6.8E-07
Depth 1m	2.5E-07	3.0E-07	1.1E-06	7.0E-08	3.0E-07	4.6E-07
Depth 10 m	4.2E-08	1.3E-07	2.7E-07	8.0E-09	7.0E-08	1.7E-07
Depth 30 m	1.2E-08	5.0E-07	1.3E-07	2.0E-09	2.0E-08	
Compressibility, a(v), 1/kPa						
Depth 0.1 m	3.2E-01	2.2E-02	1.4E-04	1.8E-01	2.0E-02	9.0E-03
Depth 1m	6.5E-02	2.2E-02	3.0E-03	5.5E-02	1.1E-02	1.1E-02
Depth 10 m	1.0E-02	1.1E-02	1.2E-04	6.5E-03	1.3E-03	1.3E-03
Depth 30 m	3.5E-03	3.0E-03	8.0E-06	1.9E-03	3.8E-04	4.0E-04
Compressibility, m(v), 1/kPa						
Depth 0.1 m	7.09E-02	5.09E-03	7.54E-05	4.55E-02	3.66E-03	1.68E-03
Depth 1m	1.44E-02	5.09E-03	1.62E-03	1.39E-02	2.01E-03	2.05E-03
Depth 10 m	2.22E-03	2.54E-03	6.46E-05	1.64E-03	2.38E-04	2.43E-04
Depth 30 m	7.76E-04	6.94E-04	4.31E-06	4.80E-04	6.95E-05	7.47E-05
Coefficient of Consolidation, sq cm/s						
Depth 0.1 m	1.60E-04	4.50E-04	2.70E-02	7.50E-05	7.00E-05	4.00E-04
Depth 1m	1.50E-04	6.00E-04	1.70E-03	5.50E-05	1.00E-04	2.00E-04
Depth 10 m	1.50E-04	4.20E-04	3.50E-03	3.60E-05	1.90E-04	3.00E-04
Depth 30 m	1.20E-04	5.50E-04	2.00E-02	3.00E-05	1.90E-04	

Table 5.1. Summary Results (Cont.)

SAMPLE	16A	18A	22	22A	28
Specific Gravity	2.79	2.77	2.78	2.77	2.78
% finer than .074 mm	90	96	96	92	97
% finer than .002 mm	53	53	50	52	52
%Sand	10	4	4	8	3
%Silt	37	43	46	40	45
%Clay	53	53	50	52	52
Initial water content in %	145	159	177	130	123
Initial void ratio [e=Gw]	4.04	4.40	4.92	3.61	3.42
Initial porosity [n=e/(1+e)]	0.80	0.81	0.83	0.78	0.77
Initial bulk density[=(G+Se)/(1+e)]	1.36	1.33	1.30	1.38	1.40
Liquid Limit	136	142	142	122	108
Plastic Limit	51	54	58	47	43
Plasticity Index	85	88	84	75	65
Activity	1.60	1.66	1.68	1.44	1.25
Liquidity Index	1.10	1.19	1.42	1.11	1.23
Compression Index	1.17	1.24	1.35	1.12	1.07
Rebound Index	0.1	0.10		0.11	0.07
Preconsolidation Stress, kPa	6.0	7.0	9.0	7.0	7.0
Bulk Density, gm/cc					
Depth 0.01m	1.36	1.34	1.31	1.37	1.37
Depth 0.1 m	1.36	1.34	1.32	1.38	1.38
Depth 1m	1.39	1.35	1.33	1.39	1.40
Depth 10 m	1.50	1.45	1.41	1.47	1.49
Depth 30m	1.61	1.54	1.48	1.56	1.58
Porosity					
Depth 0.01m	0.80	0.81	0.83	0.79	0.79
Depth 0.1 m	0.80	0.81	0.82	0.79	0.79
Depth 1m	0.78	0.80	0.81	0.78	0.78
Depth 10 m	0.72	0.75	0.77	0.73	0.72
Depth 30m	0.66	0.69	0.73	0.68	0.67
Hydraulic Conductivity, cm/s					
Seafloor interface-estimated	5.6E-07	9.0E-07	8.0E-07	3.2E-06	3.0E-06
Depth 0.01m-measured	5.4E-07	9.0E-07		8.0E-06	1.2E-05
Depth 0.1 m	5.6E-07	7.5E-07		2.7E-06	2.0E-06
Depth 1m	3.0E-07	6.2E-07		1.2E-06	5.2E-07
Depth 10 m	4.0E-08	8.6E-08	1.9E-07	1.4E-07	1.2E-07
Depth 30 m	1.5E-08	2.3E-08	5.2E-08	4.2E-08	4.1E-08
Compressibility, a(v), 1/kPa					
Depth 0.1 m	1.6E-03	1.7E-01	1.0E-01	7.1E-03	1.3E-02
Depth 1m	9.0E-03	7.0E-02	7.0E-02	4.9E-03	5.5E-03
Depth 10 m	1.2E-03	1.70E-02	1.9E-02	1.1E-03	1.2E-03
Depth 30 m	3.8E-04	3.5E-03	5.1E-03	3.1E-04	3.1E-04
Compressibility, m(v), 1/kPa					
Depth 0.1 m	3.22E-04	3.28E-02	1.74E-02	1.48E-03	2.67E-03
Depth 1m	1.81E-03	1.35E-02	1.22E-02	1.02E-03	1.13E-03
Depth 10 m	2.41E-04	3.28E-03	3.31E-03	2.30E-04	2.46E-04
Depth 30 m	7.64E-05	6.76E-04	8.88E-04	6.48E-05	6.36E-05
Coefficient of Consolidation, sq cm/s					
Depth 0.1 m	1.60E-03	2.80E-04		3.90E-03	7.00E-04
Depth 1m	1.60E-04	4.60E-04		1.70E-03	4.60E-04
Depth 10 m	1.40E-04	2.10E-04	4.40E-04	4.10E-04	3.90E-04
Depth 30 m	1.00E-04	1.95E-04	3.50E-04	4.10E-04	3.90E-04

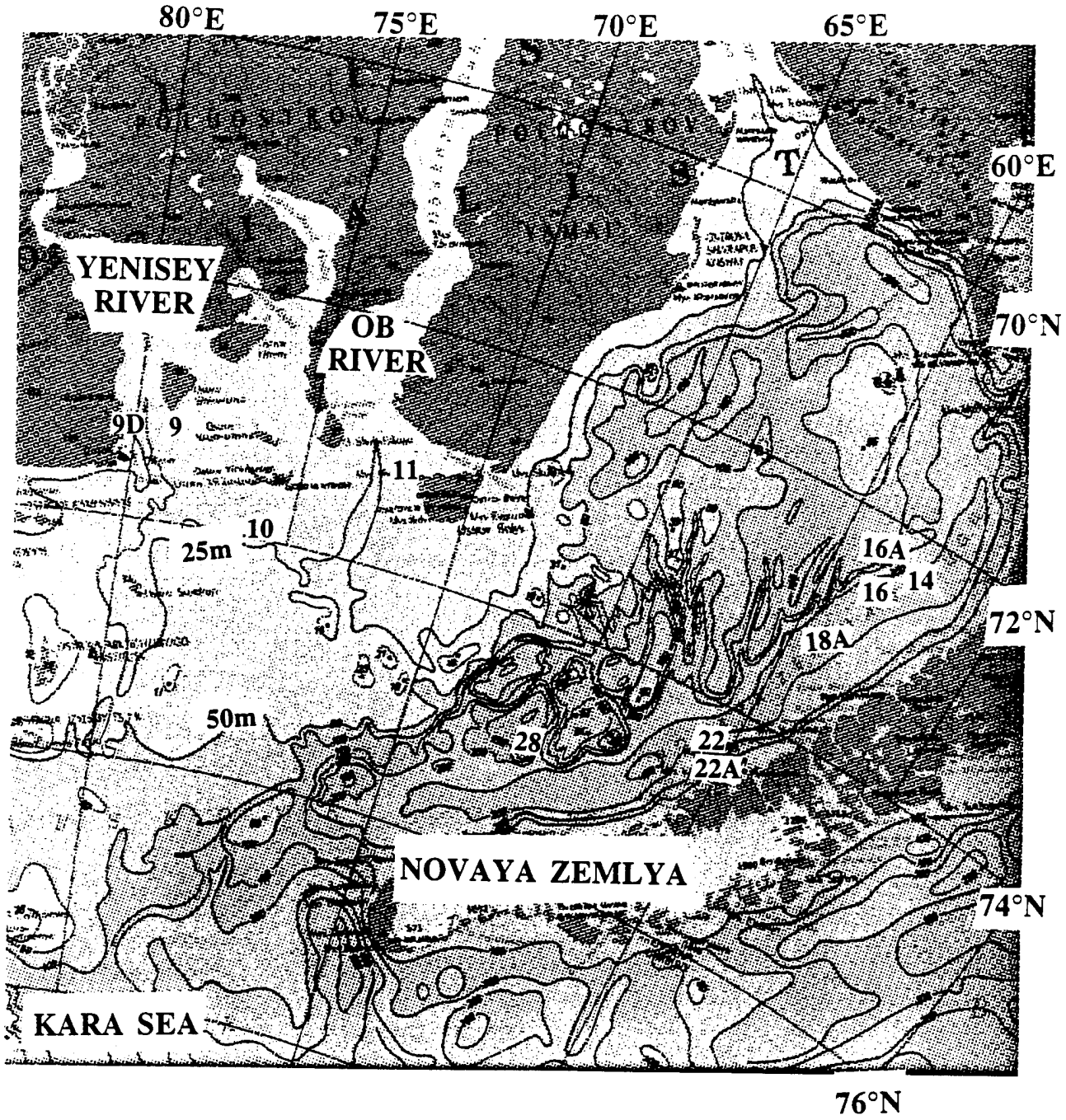

Figure 5.1. Kara sea map showing location of box core stations.

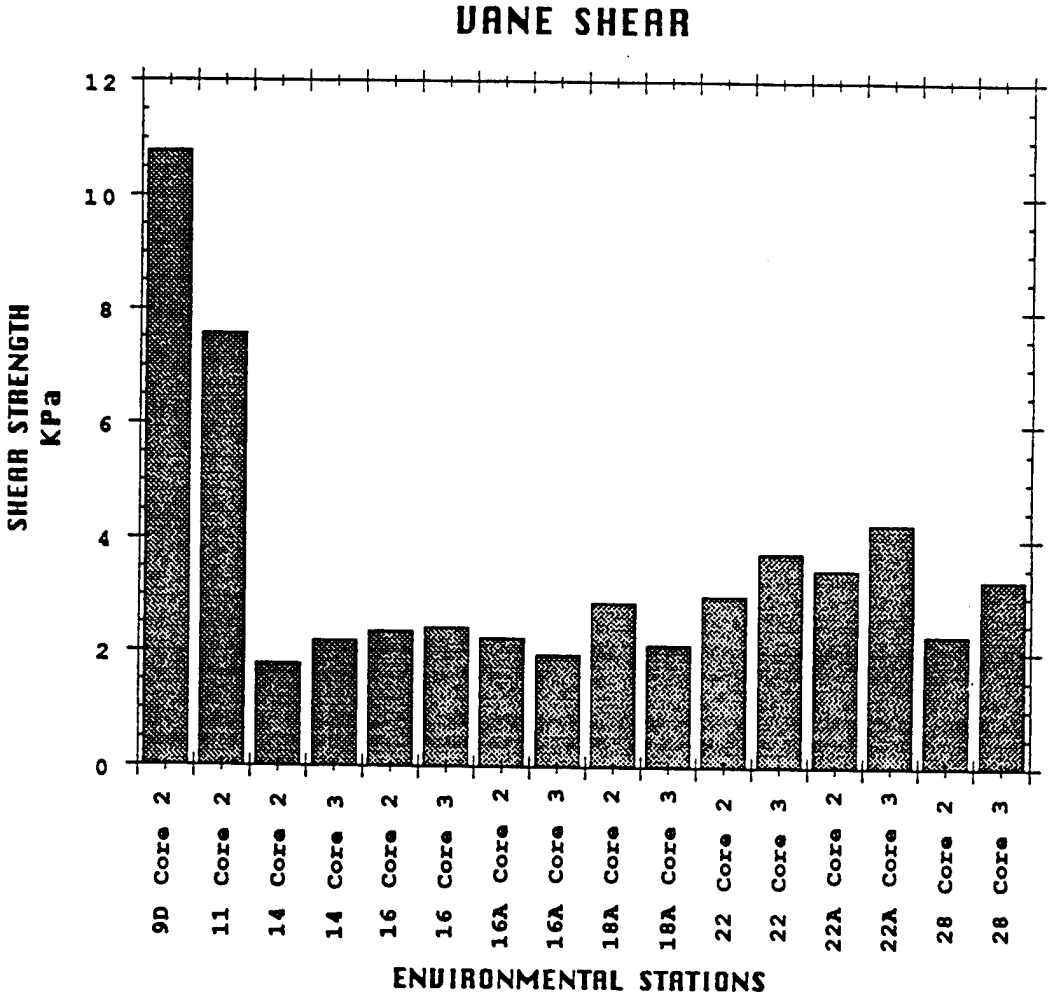

Figure 5.2. Vane shear strength (kPa) of cored sediments.

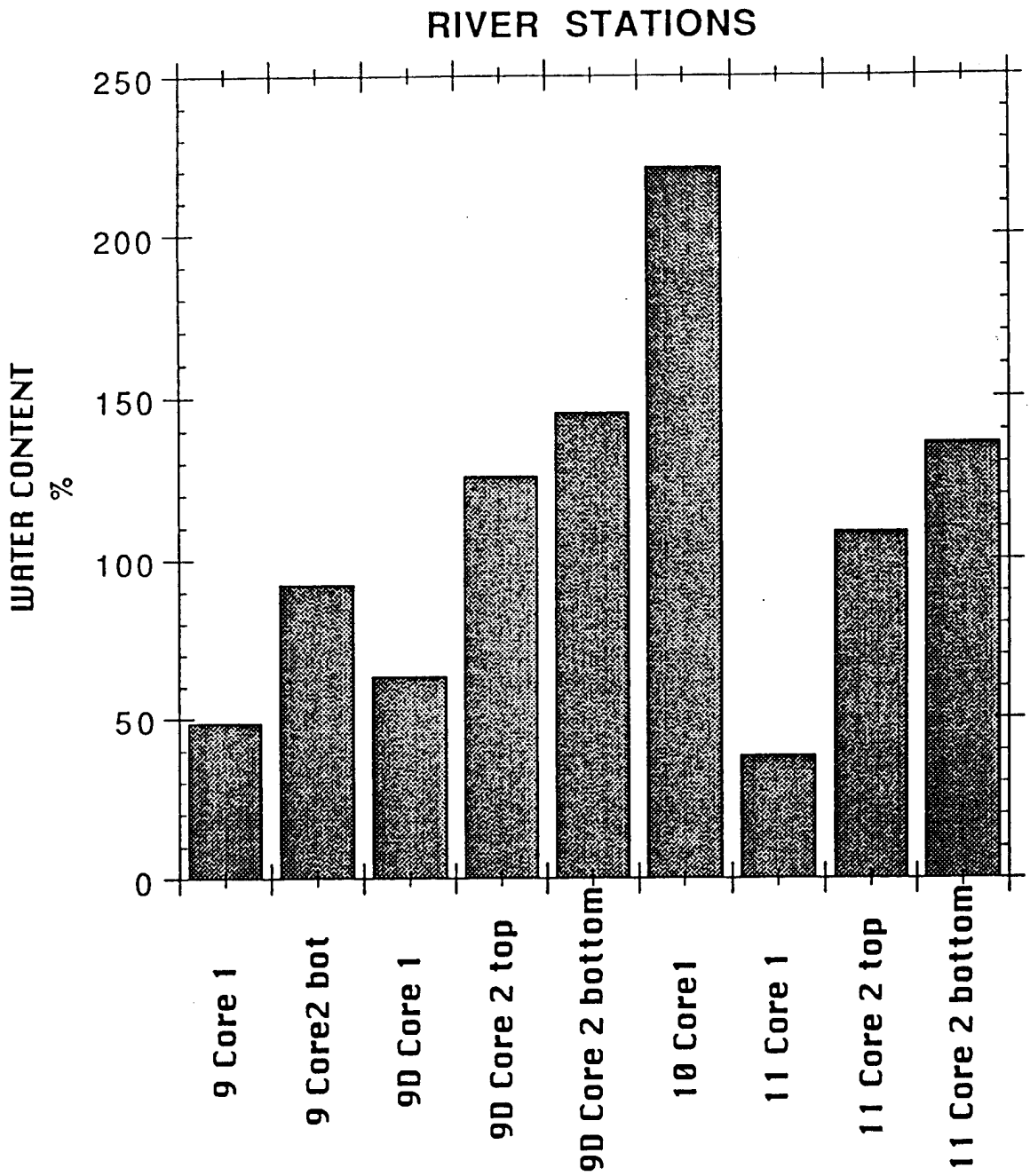

Figure 5.3. Water content of river stations.

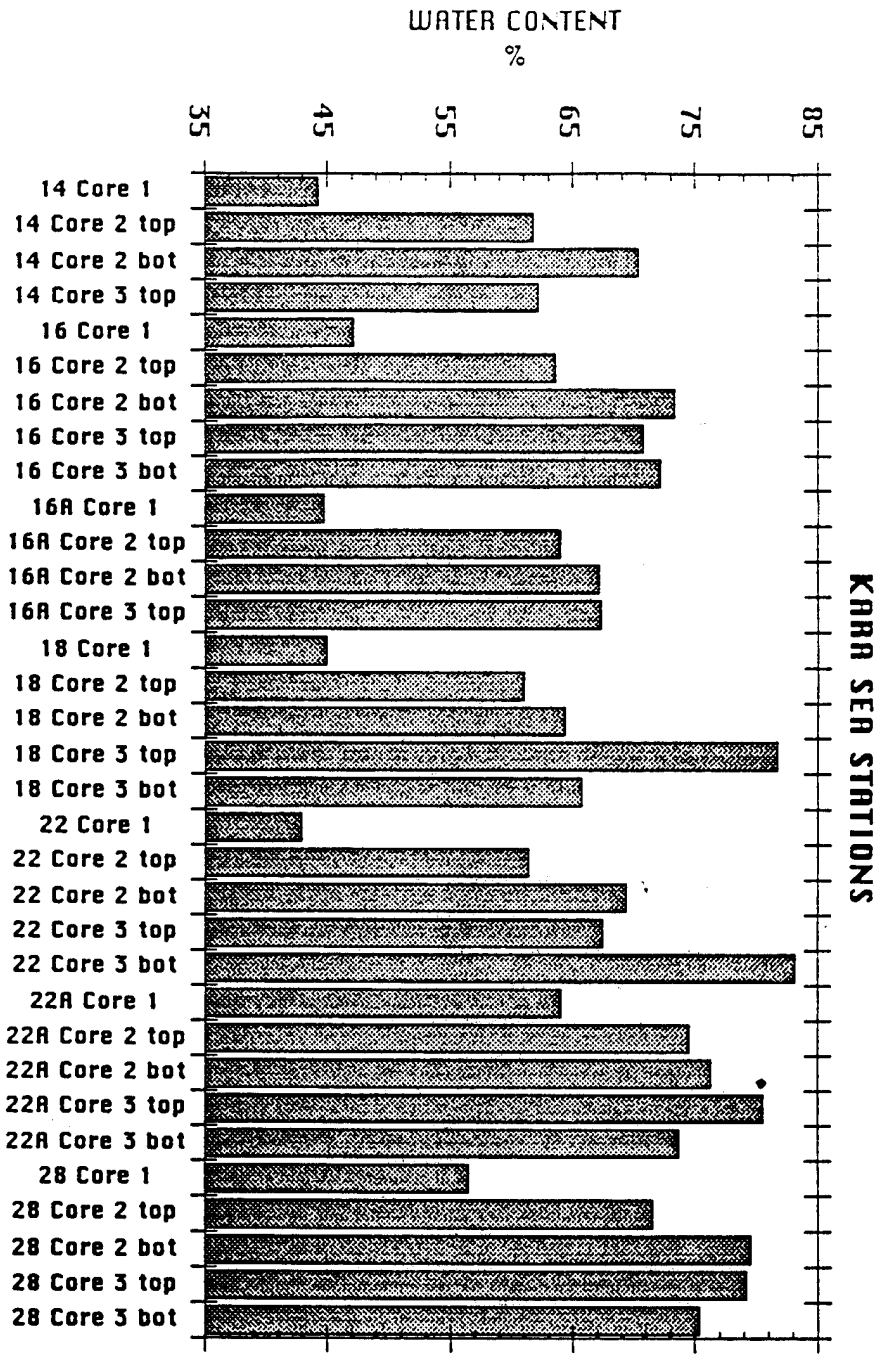

Figure 5.4. Water content of deeper water stations.

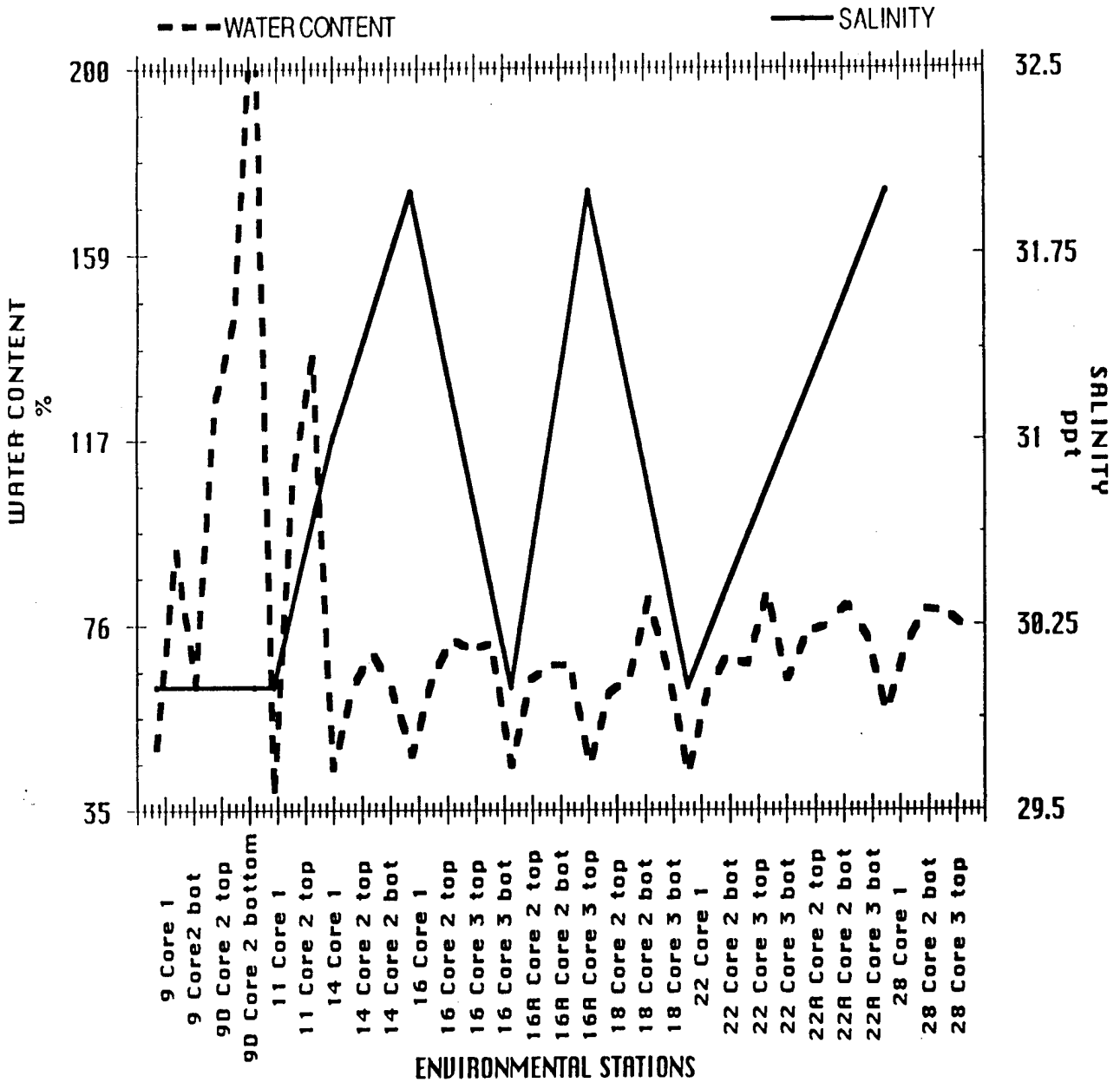

Figure 5.5. Water content and salinity for environmental stations.

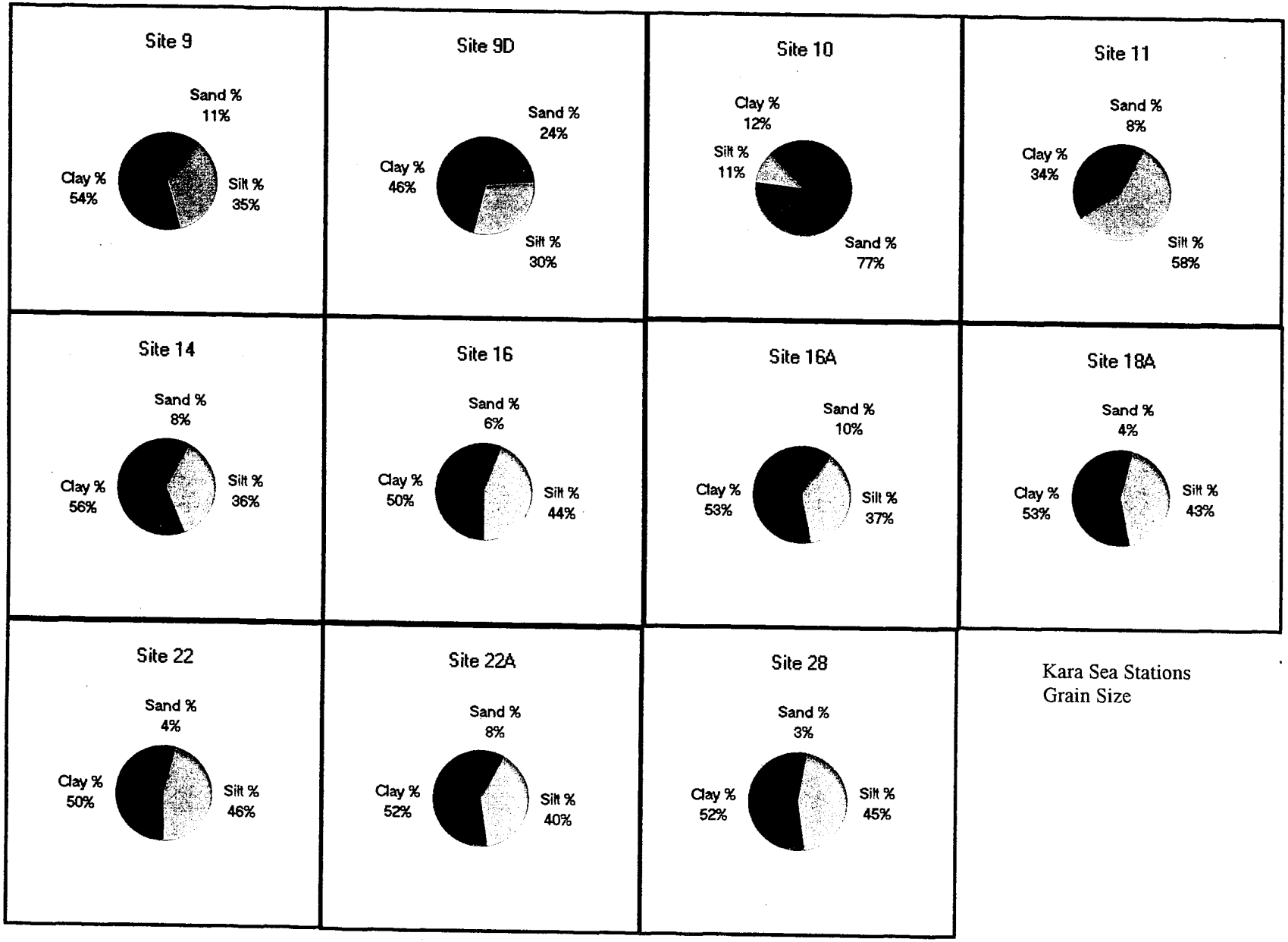

Figure 5.6. Pie diagrams of percentage of sand, silt and clay composition.

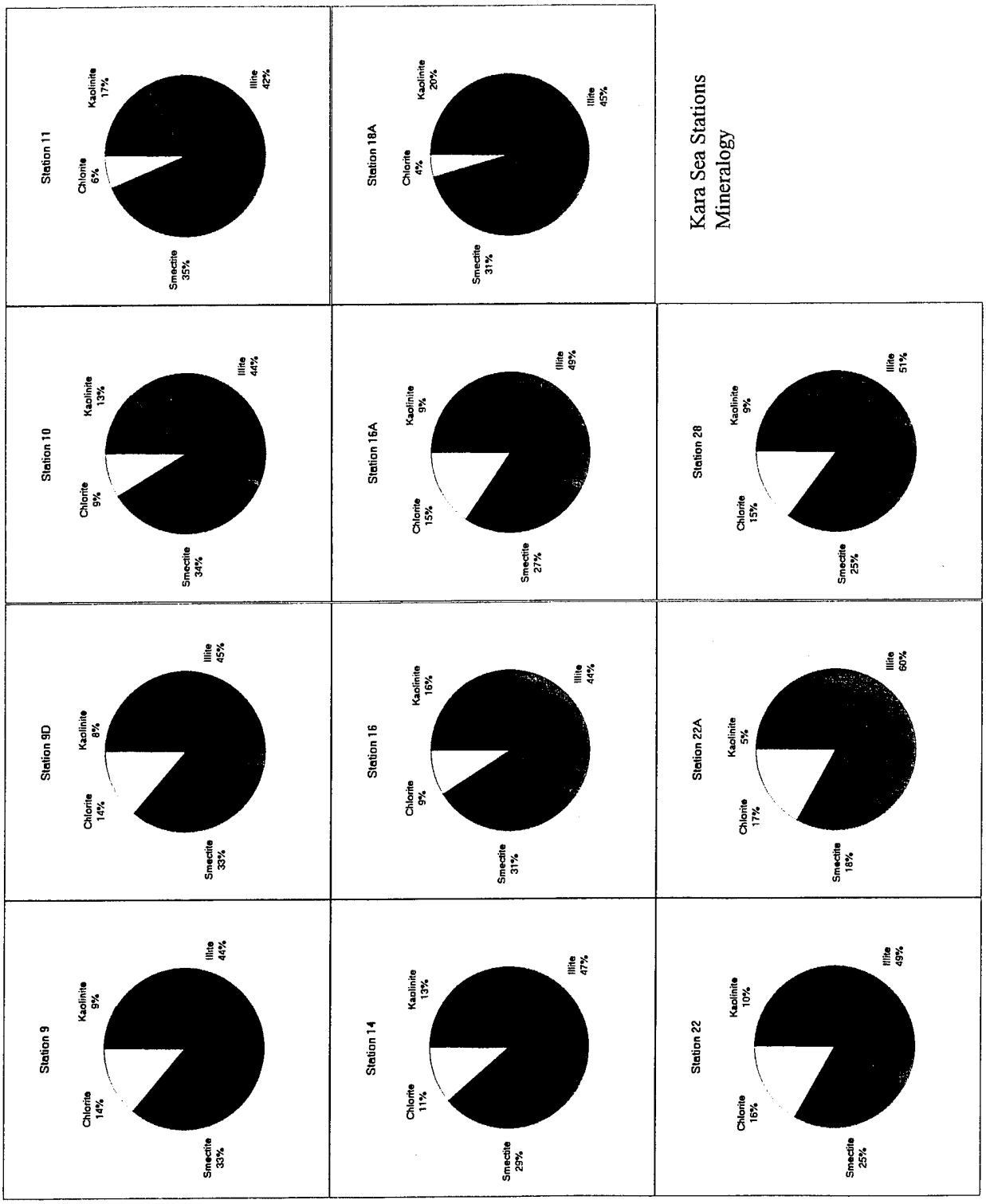

Figure 5.7. Pie diagrams of percentage of clay minerals of the fine (clay sized) fraction for environmental stations.

6. 1994 Kara Sea Region Field Experiments

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Progress on this project is reported in a classified addendum.

7. 1995 Kara Sea Region Field Experiments

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I. Narrative Documentation

A. Long term goals

The goals are to characterize the radioactivity levels in the Kara Sea region to assess the long term monitoring requirements and to assess the importance of the surface layer flow of riverine waters into the Kara Sea and of the benthic boundary layer currents on the transport, distribution and fate of nuclear pollutants.

B. Objectives of this effort

The objectives of this expedition are two-fold and detailed as follows:

1) *To develop an understanding of the circulation characteristics, including advection, mixing and dispersion, of Kara Sea waters, and of its interaction with adjacent seas.* The relationship between currents, wind forcing, tidal forcing, density structure, and sediment resuspension are all needed for this understanding. This data will be utilized in the modeling of the transport of radionuclides in the Kara and adjacent seas. Another issue to be investigated is the ice motion in the Kara sea, the impact of the Siberian Costal Current on the ice and the possible sediment transport via sea ice into the Arctic basin.

2) Quantify and characterize the radioactivity levels in the Kara Sea sediments and water column in order to establish the requirements for long term monitoring. This includes tracking the activity from the Yenisey river eastward and investigating the relationship between marine geology, sediment type and the accumulation of radioactivity in the sediments. This work will be

done by quick-look analysis on board ship and by low-level laboratory measurements of water samples, filtrates, sediment and biological samples.

C. Approach

This is a cooperative program with the Norwegian Defense Research Establishment (NDRE). We have an agreement with NDRE to conduct a 5 week expedition into the Kara Sea on board the H.U. Sverdrup II. This ship is a Norwegian government vessel dedicated to military oceanography and as such is well equipped for such an expedition. NRL will share 50% of the direct ship cost with NDRE covering 50% of the direct cost and 100% of the indirect cost. Our mission will benefit from the assistance of the 5-6 NDRE personnel on board and the sharing of data they are collecting. We have also established a cooperative agreement with the IAEA. One scientist from the IAEA will participate in the cruise. The IAEA will also provide added radionuclide data analysis capabilities.

In order to study the surface currents, 24 Argos tracked drifters will be deployed within the Kara Sea and its adjacent seas. At issue for the drifter program are the following: 1) surface circulation within the southwestern Kara Sea and the influence of the Norwegian coastal current inflow through the Kara-Gate (Proliv Karaskiye Varota), 2) dispersion of waters from the Ob/Yenisey rivers along the Siberian coast and into the Siberian Costal Current; and 3) exchange of waters with the Barents Sea and with the higher Arctic basin. Together with the along-track shipboard measurements of current with ADCP and hydrography using a CTD, 10-15 pairs of surface and bottom current meters will be deployed for the duration of the cruise. These are inexpensive, easy to deploy and retrievable instruments which have a good history of operation in coastal waters. They will be valuable for Eulerian flow characteristics pertinent to dispersion. In addition, several bottom moorings will be deployed for recovery in 1996 for the purpose of estimating the event scale bottom stirring characteristics during the ice covered time of the year. In order to monitor the sea ice motion in the Kara Sea, 6 ice hardened drifters will be deployed from the ship in such a manner as to freeze in the ice. These will be used in conjunction with Norwegian remote sensors to track the ice motion for the year. Supporting data will include chirp sonar and SIMRAD 1000 multibeam sonar for floor mapping.

The 1995 cruise plan calls for approximately 20 full environmental stations (CTD, water and box core sediment samples) and over 40 quick stations (CTD, small volume water samples, and grab samples). These stations will be distributed in the river estuaries, east of the Yenisey, the central Kara, the north eastern Kara, along the Novaya Zemlya coast and at the N1 dump site.

We are planning the first on-site determination of the distribution coefficients (K_d) for Co, Cs and Pu to be performed in the Arctic region for key radionuclides. The distribution coefficient, representing the partitioning of radioisotopes between dissolved and particulate phases, is a fundamental link in the understanding of the transport of radionuclides in the Arctic seas and for the risk assessment calculations. Present calculations use values that have been determined in the laboratory. Radiological analysis will include ^{137}Cs and any other γ-ray emitting isotopes, ^{90}Sr, ^{129}I and Pu isotopes. The data analysis will be conducted by NRL, NDRE, and IAEA. We

have an agreement with Linas Killius of the University of Toronto Isotrace Laboratory to cooperate on the analysis of ^{129}I water samples.

D. Accomplishments

The Kara expedition is set for 26 August - 1 October 1995.

E. Results

This is a new program and will soon have results from the 1995 expedition. The results of pervious NRL field work is in a classified appendix.

F. Impact for science or systems applications

This research should provide new insight on the formation and maintenance of coastal fronts due to river plume interactions with continental shelf waters. In the Kara Sea this front extends much further than could be expected from scaling associated with the Rossby Radius of Deformation. It has been suggested that a current jet, at the edge of the Yamal Delta, prevents the further spreading of this water, creating a soft barrier and a front connected to the break in topography. The current jet may be due to the 'Neptune Effect,' an interaction between pressure and sloping topography. The upcoming cruise should provide needed data for the understanding of this effect.

In addition the determination of distribution coefficients may have a significant impact on the relative importance of various radionuclide transport mechanisms.

H. Relationship to Other Projects

The planning for this expedition has been based in part on the Modeling Requirements Workshop for Water Mass Dynamics, Ice and River Transports in the Kara Sea. The expedition has been designed to provide model validation data. The determination of distribution coefficients (K_d) will have direct impact on the risk assessment calculations. The results from this expedition will provide model validation for R. Preller's Modeling effort. The results will be incorporated into NRL's GIS database for the ANWAP program.

I. Application to the Arctic Radioactive Waste Assessment Program

The physical oceanographic observations are needed in order to properly formulate a valid predictive computer simulation of radionuclide-pollution dispersal in the Arctic basin and adjacent seas. Boundary conditions, validation and correct formulation of mixing parameters are at issue. Building on previous successful work, this work will be conducted in close cooperation with Dr. Ruth Preller's numerical modeling program and with Norwegian colleagues who are developing physical models of the Kara sea. The radionuclide data are needed to better determine the long term monitoring requirements. The K_d values are needed in determining the transport of

radionuclides and the pathways. Preliminary evidence indicates a wide variability of K_d values within the Kara Sea.

II. Statistical Information

A. List of publications

T. McClimans, D.R. Johnson, Ø. Grenness and S.E. King, "Fresh water masses in the Kara Sea" submitted to the Journal of Marine Systems.

D. Presentations

T.A. McClimans, D.R. Johnson, and Ø. Grenness, "Processes in regions of fresh water influence" 27th International Liege Colloquium on Ocean Hydrodynamics, May 1995.

D.R. Johnson, T.A. McClimans, and Ø. Grenness, "Fresh water masses in the Kara Sea," Workshop on Modeling Requirements for Water Mass Dynamics, Ice and River Transports in the Kara Sea, 26-30 June 1995, Tjome, Norway.

D.R. Johnson, T. McClimans Ø. Grenness and S.E. King, "Circulation of the Kara Sea" EQU-96

D.R. Johnson, T. McClimans Ø. Grenness and S.E. King, "Wind driven sea ice dynamics of the Kara Sea" Oceanography Society Conference-96

G. Russian contribution to monitoring program

NDRE has invited 3 scientists and one Naval officer to participate in a Trilateral Expedition. While participation is unlikely in 1995, we plan to share the data from the expedition with our Russian Naval counterparts. It is hoped that the mechanism for cooperation can be worked out for 1996.

8. Radionuclide Monitoring Technologies and Strategies

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I. Narrative Documentation

A. Long term goals

The long-term goal is to produce improved and innovative methods for monitoring radionuclide levels in the Arctic.

B. Objectives of this effort

The primary objective of this task is to investigate technologies for marine radiation monitoring and to develop a monitoring system appropriate for the Arctic environment. Supporting subtasks include: a) to determine the potential capabilities of new detector technologies suitable for monitoring marine radioactivity; b) to transition an existing sensor to a system appropriate to the Arctic; c) to conduct prototype testing; and d) to identify those year-long oceanographic data essential to the prediction of anthropogenic radionuclide transport, concentration and deposition to enable a risk assessment of the radioactivity in the Arctic.

C. Approach

The approach for this task is two-fold. The first part of the program was information gathering. To this end we organized the Workshop on Radionuclide Monitoring in the Marine Environment to provide a forum for addressing many of the monitoring issues. The workshop was used to gather information about existing monitoring technologies, to promote dialog on the merits of monitoring strategies and to determine the data requirements for radiological hazard assessment and transport modeling. This also included a review of new promising technologies with potential to enhance the radionuclide monitoring capabilities.

The second part of the program was to evaluate the most promising technologies, to select a sensor and monitoring design concept and to procure and test a prototype system. The detector technology review and evaluation of sensors has been completed and the effort is now focused on the acquisition of a new monitoring system based on the findings of this program. The design and procurement of a prototype system are underway.

To insure the effectiveness of this program, a collaboration has been developed between the Naval Research Laboratory (NRL) and the IAEA Marine Environments Laboratory (MEL). In this collaboration, both design efforts and monitoring data will be shared between labs. A potential future collaboration may include the Kurchatov Institute. A meeting is planned in the fall to discuss a monitoring project for Stepovogo Bay using Russian instrumentation.

D. Accomplishments

Monitoring Workshop: The Workshop on Monitoring of Nuclear Contamination in Arctic Seas was held 18-19 January 1995 at NRL to specifically address long-term anthropogenic radionuclide monitoring in the marine and especially the unique Arctic environment. The workshop was organized and chaired by Steven King. Invitations to this workshop were extended to participants in the ONR Arctic Seas program and to other experts in the field. The goals included fostering discussions on the requirements of Arctic monitoring and promoting better cooperation among the ONR program participants towards this goal. The workshop included sessions on nuclear instrumentation, radiological hazard requirements and data requirements for the validation of transport modeling. A final panel-led discussion on monitoring generated much discussion.

The workshop brought together over 100 detector R&D scientists, communications and systems engineers and Arctic researchers. Thirty eight presentations were given at the workshop. Based on the enthusiastic response of many of the participants, the workshop was a great success. The presentations given at the workshop have been published in a proceedings limited quantities of which are still available from NRL.

One goal of the workshop was to identify those parameters which are essential to the prediction of the final destination of anthropogenic radioactive materials that are now in the Arctic seas or that may enter the Arctic seas from the Arctic rivers. The workshop addressed the choice of locations for monitoring sites, the determination of monitoring capabilities requirements, and identified existing platforms, communications, and other systems that could meet the monitoring requirements. Monitoring scenarios could include year-long deployments of bottom-fixed stations or the use of Autonomous Underwater Vehicles. Methods for collecting radionuclide samples over a one-year period for laboratory α and β measurements were also considered.

New Radionuclide Monitoring Technologies: An integral part of the overall strategy is the identification of suitable nuclear instrumentation for the monitoring requirements. The choice of sensor for use in an Arctic environment took into account various design limitations. The important parameters include operating temperature, the effects of motion and vibration, the operating characteristics (voltage and power), the sensor sensitivity, efficiency, size, and energy

resolution. After choosing the most viable detector candidate(s), small demonstration system(s) were tested to determine their performance characteristics in a marine environment. Parameters such as energy resolution, efficiency, ruggedness, power consumption, and stability were evaluated.

The review of existing detector technologies was completed. Prototype devices in ruggedized, waterproof housings were procured. Five different detectors were selected for performance evaluation: a NaI scintillator with PMT, a CsI scintillator with a photodiode and two types of CdTe and CdZnTe semiconducting detectors. The detectors were tested in air, distilled water and sea water. Sensitivity, that is the ability to detect a specific isotope above the environmental background, was a principal parameter. Other parameters measured were efficiency and energy resolution. Testing of these devices has been completed.

Based on the detector research the only detector viable at present for an Arctic monitoring station is NaI housed in a rugged casing, with signal temperature correction electronics, low power electronics and integral spectrum analyzer. A commercially available sensor has been identified to meet the requirements. The sensor will be integrated with an Autonomous Expendable CTD (AXCTD). This mooring station can be deployed from a ship of opportunity, slowly sink to the bottom and remain deployed for a programmable length of time collecting data. At a predetermined time or set of conditions, the sensor system will rise to the surface and transmit the year's accumulation of data via ARGOS to NRL. The data collected includes gamma ray spectra taken during 24 hour periods, temperature and salinity acquired every 3 hours. Because of battery limitations the detector will have a 50% duty cycle. On an average day a 12 hour spectra will be acquired. This spectra will be taken in shorter intervals to ensure uniform coverage throughout the day. The sensor and platform will handle power management. If an unusual event occurs, the data acquisition rate will increase, or if the power consumption is too great, the data acquisition rate will be slowed. If the opportunity exists, the buoy can be recovered, batteries replace and redeployed. However, the intention is to produce a package design that could be considered expendable.

E. Results

Some of the general guidelines for developing a monitoring system derived from the workshop include:

- Keep it simple. ^{137}Cs is the most detectable of the relevant isotopes to monitor. Any monitoring of beta or alpha emitter would require more development.

- Determine the mission: risk assessment, transport model verification, open scientific questions, or policy requirements. Design the system to meet the mission goals. Since Russian are considering large NaI sensors powered from and transmitting to shore via armored cable, we chose to develop a smaller system that could be deployed at any site from a ship of opportunity. The design described above avoids the difficult

communication problems through the ice while at the same time giving year-round coverage of an area.

- Target specific locations. Areas under consideration are the Ob/Yenisey rivers, the Novaya Zemlya trough, the Kara Gate and along the Siberia coast.

- Provide time series data of both radioactivity and oceanographic parameters such as current, temperature, salinity and light transmissivity for observation of the dynamic annual changes in the Arctic regions. To monitor for specific isotopes, an energy resolving monitor is required. Monitoring of ice floe movement, sediment transport, and assay of radioactivity were also desired but no suitable solution was presented.

Sensor Evaluation

During the evaluation of the prototype detectors, each one with the exception of the NaI scintillator were returned to the manufacturers for repair. The detectors were found to be more sensitive to vibration and minor shocks than expected. In particular the CdTe and CdZnTe were both susceptible to microphonic vibrations. The best resolution was obtained with the CdTe detectors using a charge compensation circuit. Figure 8.1 shows both the NaI and CdTe spectra. While this resolution helps in isotopic identification it does not compensate for the loss of counts due to the small detector size in terms of detector sensitivity.

The following chart summarizes the detector data:

Detector	Voltage	Efficiency	Resolution	Size	Sensitivity	Atomic No
	(volts)	(%)	(%)	cm^3	Bq/m^3	(avg.)
NaI	1000	9.05	8.23	58.06	7.3	32
CsI	70	8.8	8.6	3.24	123	54
CdTe	700	17.02	4.2	.5	10000	50
CdZnTe	60	15.5	3.98	2.25	N/A	49

The detector sensitivity is calculated based on a uniformly distributed source in sea water and a 24 hour counting time. The calculation of sensitivity assumes isotropically uniform. For CdTe this would require the use of three of the planar detectors to achieve. Thus for the detection of one order of magnitude increases of ^{137}Cs above background in sea water, a NaI detector must be used or multiple detector arrays of the other detectors tested. If the only purpose of a monitoring detector was to detect high levels of ^{137}Cs then the other detectors become viable candidates.

F. Impact for science or systems applications

The development of the monitoring technology in this task will provide a new year-round monitoring capability for radionuclide transport and physical oceanography in the Arctic. This monitoring platform should also provide a new option for other programs requiring long term data in Arctic waters. It could be used to monitor chemical pollutants such as hydrocarbons or PCBs, to collect physical oceanography data or in other applications with similar requirements.

G. Transitions accomplished or expected

We have obtained the interest and cooperation of two companies, Oceanor and Ocean Sensors for the development of a monitoring station meeting the program requirements. Technology transitions expected from this task include a commercially available radiation monitoring station adapted to the marine environment. The radiation sensor could be utilized for the Navy's underwater RADIACs. The RADIACs are used by Navy divers during dives where radiation hazards are present. The technology could be utilized for radiological accident emergency response and rapid response to suspected dumping of nuclear materials

H. Relationship to Other Projects

This task is integrated with the other NRL ANWAP tasks. Information from the Modeling, GIS and field experiments tasks were utilized in developing the monitoring strategies. Data from a deployed monitoring system will be incorporated into the GIS database. It is anticipated that the first deployment will be on the NRL/NDRE 1996 cruise. In addition all project leaders in the Arctic Nuclear Waste Assessment Program (ANWAP) were invited to contribute to the Arctic Monitoring Workshop. Collaborations with the IAEA should leverage the effort in this program in the future.

I. Application to the Arctic Radioactive Waste Assessment Program

This effort is focused on providing ANWAP with new capabilities for monitoring radioactivity in the Arctic and adjacent seas. This monitoring capability is not presently available for the marine environment. It is needed to provide data for modelers in order to develop a better understanding of the radionuclide transport processes and to provide timely information any increased activity which may occur episodically in the Arctic Seas.

Known measurement/monitoring efforts in the Kara Sea have been conducted only during the open water period; thus radionuclide transport potential during the nine-month ice-covered period is largely unknown. A monitoring effort is needed to understand the annual cyclical events as well as provide reliable data of variations in the release of radionuclides. In an environment with such dramatic annual and transient changes, the use of only ship based measurements is inadequate for the assessment of the nuclear contamination problem.

II. Statistical Information

A. List of publications

S.E. King, Editor & Chairman, "Proceeding of the Workshop on Monitoring of Nuclear Contamination in Arctic Seas," NRL/MR/6610--95-7674, (1995).

S.E. King and G.W. Phillips, "New Detectors for Monitoring," Proc. Work. On Mon. Nucl. Cont. in Arct. Seas, NRL/MR/6610--95-7674 (1995) IV/110 - IV/130.

D. Presentations

S.E. King, R.A. August, G.W. Phillips, U. Aakenes, R.C. Mania, "New Detectors for Monitoring," presentation at the Workshop on Monitoring Nuclear Contamination of the Arctic Seas, NRL, Washington, DC, 18-19 January, 1995.

S.E. King and G.W. Phillips, "Monitoring of Arctic Contamination," Arctic Nuclear Wastes Assessment Workshop, Woods Hole Oceanographic Institute, Woods Hole, MA, 1-4 May 1995.

E. Committed Service

Chairman for the Workshop on Monitoring Nuclear Contamination of Arctic Seas

G. Russian contribution to monitoring program

There is no direct Russian participation in this component at present. Plans are underway to develop a cooperative program between the Kurchatov Institute, IAEA-MEL, NRL and others for deployment of a monitoring system in Stepovogo Bay.

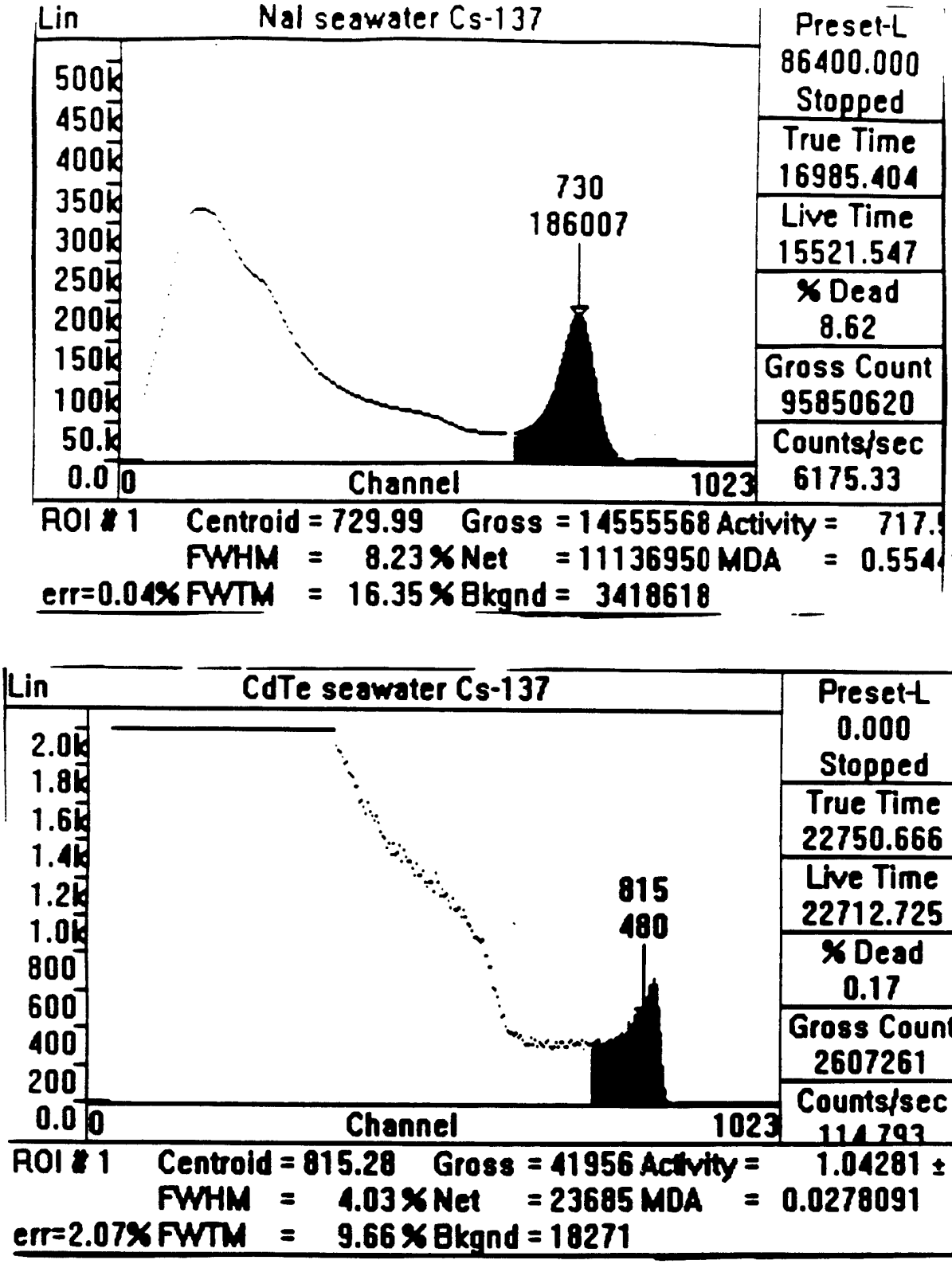

Figure 8.1. ^{137}Cs spectra from a NaI detector (top) and a CdTe detector (bottom). The CdTe detector uses a charge correction circuit.

9. Chemical and Physical Characteristics of Particulates in the Kara Sea, 1994

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I. Narrative Documentation

A. Long-term goal

To determine the potential for offshore and nearshore transport of radionuclides in the Kara Sea by adsorption to suspended particulates.

B. Objectives of this effort

1. To determine horizontal and vertical distributions of suspended mineral particles.
2. To make a preliminary assessment of trajectories of suspended mineral particles from the Ob and Yenisey Rivers.
3. To determine particulate partitioning (physical measurements and elemental composition) in relation to water structure and distance from river mouths.

C. Approach

1. Collect samples of suspended particulate populations northward from the Ob and Yenisey Rivers, within the river mouths, and near shore.
2. For each sample, analyze statistically significant numbers of individual particles for elemental composition, diameter, projected area, perimeter, and aspect ratio using SAX methodology.
3. Determine particulate abundances, size distributions and classify particles as to mineralogy based on elemental ratios.

D. Accomplishments

Suspended particulate samples were collected from 3 depths (within the surface layer, midwater transmissometry minimum, and benthic boundary layer) at stations in the Kara Sea, near the mouths of the Ob and Yenisey, and on an east-west transect along shore in October of 1994. Samples were collected concurrently with CTD/transmissometer/ fluorometer casts so that bottles could be tripped based on observed water structure. Samples from 3 depths at each of 8 stations were analyzed using SAX (Scanning electron microscope-Automated image analyzer-X-ray spectrometer) methodology. Details of sampling and preparation procedures as well as SAX methodology and instrumentation may be found in Appendix A. The results constitute the most complete description of suspended particles available for the Kara Sea.

E. Results

Figure 9.1 shows station locations. Analysis of the SAX data was restricted to particle abundances, classification of particles by mineral type, and particle size distributions.

Total particulate counts vs. depth for 8 stations are graphically summarized in Figure 9.2. In orders of magnitude, particles ranged from 10^2 to 10^5 million particles per cubic meter ($10^6/m^3$ or mp/mc) For reference, this is about two orders of magnitude higher than Lavoie (1992) measured in the Sargasso Sea using similar methodology. Particle abundances in the river mouth stations (424A, 417) and in the nearshore stations 429 and 414 were in the range of 10^4 mp/mc. Particle abundances at Station 409, at the easternmost end of the along-shore transect, were significantly higher in the surface mixed layer, and the bottom waters at this station exhibited the highest concentration of particles the entire data set, about 2 x 10^5 mp/mc. All of the plume concentrations were less than found in the surface and bottom waters at each station, suggesting that particulate load was not correlated to transmissometry.

Conclusion: The term "plume" in the sense of river-borne particulates trapped at a density surface is probably erroneous for this area at this time of year.

Moving along a northwestward transect from the mouth of the Yenisey - Stations 414, 404C, 403D, and 403A - particle abundance appears to decrease with distance from the mainland. Most of the particulates appear to be in the surface layer to the south, but the distribution with depth become more even as one goes northward.

Conclusions: The higher concentrations in the Kara Sea than are present in the river mouths are consistent with a recent pulse input of suspended solids. The input was to the surface waters of the Kara Sea and may have been air-borne, but equally may have been river-borne. D. Johnson (1995, personal communication), in his analysis of water mass transport, found Ob river water to be trapped in an uncoupled surface layer that extends much further north than predicted by the inertial radius due to wind-induced turbulence. Although mass balance calculations have not been made, it seems likely that the source of the mid-water and bottom particulates in the Kara Sea proper is the sinking of particulates from the surface, with a net loss

to the sea bottom. The high particulate load at Station 409 may be due to the same pulse input, or, more likely, due to input from the Yenisey. This conclusion needs to be tested against Johnson's hydrographic model.

A preliminary analysis of mineralogical class by station and depth are presented in Figures 9.3a-h. Iron-rich clays are by far the numerically predominant class of suspended particulates throughout the study area, with siliceous particles (quartz or diatoms), other clays, and metallic sulfides generally the next most abundant classes. Single-class predominance is less pronounced in mid-water plume samples than in surface and bottom samples. There is no clear pattern in the preliminary data that would indicate whether spatial partitioning of mineralogical types is occurring in the study area or whether the inputs from the two rivers can be differentiated for the purpose of determining particle-load trajectories.

Conclusions: The elemental analysis must be refined to better identify the iron-rich mineral particles. This will include comparison to x-ray diffraction results of the sediments in the area. Statistical analyses need to be performed on the existing data to determine confidence limits for intercomparing these samples.

Particle size distributions (PSD) generally exhibited peaks in the range 0.8 - 2 mm diameter (i.e., diameter of a circle with the equivalent area of the particle measured). Figures 9.4-9 present PSD expressed as projected area, a measure more pertinent to the question of radionuclide adsorption.

Conclusion: PSD's are consistent with a predominantly clay particle population.

F. Impact for science or systems applications

The data set consists of thousands of "object vectors", each of which is a list of chemical and physical measurements for an individual particle. This rich data matrix has the potential for providing basic parameters needed for modeling sediment/contaminant transport and optical properties in the study area.

G. Transitions expected:

None planned at this time.

H. Relationship to other projects

This study was performed in conjunction with the Kara Sea physical oceanography and benthic ecology research conducted by NRL and in collaboration with NRL' s sediment mineralogy study.

I. Application to Arctic Radioactive Waste Assessment problem

Estimates of partitioning and transport of adsorbable radionuclides and other contaminates in the Kara Sea require a knowledge of the particle population in the water column. The data collected in this study provide a description of this population that is unprecedented in its detail. The application to the radioactive waste problem (or others) will depend on the ability of current models to utilize the type of data available in this rich data matrix.

II. Statistical Information

A. List of publications: None to date.

B. Number of graduate students: None.

C. Patents: None.

D. Presentations: None.

E. Committed service: None.

F. Awards: None

G. Russian participation: None.

Appendix A

METHODS

Sampling

Water samples were collected in standard PVC Niskin™ bottles mounted on a rosette (all General Oceanics, Inc., Miami, FL) that also held a CTD (conductivity-temperature-depth probe, SeaBird Electronics, Belleview, WA), a transmissometer, and a fluorometer (both SeaTech, Seattle, WA). Water structure and optical properties were recorded on the down cast, sampling depths chosen on the basis of the traces, and the Niskin™ bottles were tripped on a second down cast in order to sample water uncontaminated by the hydrowire. Bottles were tripped above, within, and below the transmissometer minimum (particle maximum).

Upon retrieval of the rosette package, each Niskin bottle was removed from the rosette and inverted several times to thoroughly mix the contents (significant particle settling occurs very quickly in water sample bottles), and 100 ml aliquots were immediately drawn from the Niskins. Aliquots were filtered at about 20 inches of mercury vacuum onto 47 mm, 0.4 mm pore size Nuclepore™ (Nuclepore Corp, Pleasanton, CA) polycarbonate membranes mounted in 500 ml capacity stainless steel filter funnels fitted with stainless steel mesh filter supports (Millipore Corp, Framingham, MA). Seawater was added to the filter funnel until the filtration rate slowed significantly, 300 to 1000 ml of seawater were filtered depending on when the membrane Just before the membrane went dry, a few ml of 0.2 mm-filtered detergent solution was added to the sample to ensure even distribution of particles over the membrane. A few milliliters of freshly filtered distilled water were used to wash down the filter funnels and to dissolve salts out of the particulates trapped on the membranes. Membranes were allowed to air dry in small, plastic petri dishes. Filters and filter funnels were covered with aluminum foil during all procedures to minimize airborne particulate contamination. All containers and implements coming in contact with water samples were rinsed with freshly filtered distilled prior to use. Niskin bottles were deployed open and were considered to be thoroughly flushed at the time they were tripped.

Sample Preparation

At the laboratory, sample membranes were quartered to provide replicates. Two quarters of each membrane were archived and the other two quarters were processed as described by Lavoie (1992). Approximately 2 ml of 5% ruthenium tetroxide (RuO_4)solution were placed in the bottom a glass petri dish. Sample membrane quarters were adhered to the petri dish top using a small drop of distilled water, and the top was placed on the bottom of the dish. After 10 min exposure to the RuO_4 vapor, both membranes and the particles on the surface were impregnated with reduced Ru metal. Ruthenium impregnation eliminates the need for heavy metal coating for imaging in the SEM, does not interfere with EDXS analysis, and provides an even, dark background necessary for image analysis.

Membranes were attached to standard SEM stubs with double-sided tape, and the edges were daubed with carbon paint to provide a grounding path.

SAX

SAX is an acronym coined by Johnson (1983) to describe a methodology for particle analysis made possible by integrating three existing hardware systems and methodologies: scanning electron microscopy (SEM), energy dispersive x-ray spectrometry (EDXS), and automated image analysis (AIA). Hence, SAX stands for Scanning electron microscopy with Automated image analysis and X-ray energy spectroscopy. Using a special interface, the SEM and EDXS are controlled by a computer which also performs the image analysis. The system can count, size, and classify on the basis of operator-specified criteria on the order of 400 particles per hour, roughly 10 times the speed of a computer-aided human analyst. The result is a multidimensional data matrix of descriptors for the entire population of particles. The most important dimension for the purposes of this report is the classification determined by the elemental ratios. If the particle population has a distinct elemental ratio signature, that population can be tracked as it is dispersed in the environment. Johnson (1980, 81) demonstrated such an application for aeolian particles. Lavoie (1992) showed the feasibility of the technique in the marine setting.

SAX is a feature oriented, real-time technique (Lee and Kelly, 1980). It is analytical in that it extracts quantitative information about observed, individual features (Jones and Smith, 1978; Johnson, 1983). In contrast to image analysis techniques that operate on a stored image (usually a photograph or a digital image file), SAX operates in an "active" image acquisition mode: all analyses are performed and recorded while the sample is under the SEM electron beam. Although this approach is slow relative to modern image frame analyzers, it avoids problems with image drift, thus enabling elemental analyses to be unambiguously associated with individual particles. In addition, elemental analyses are more quantitative than can be done using a correlation of atomic weight to gray scale, which is the usual approach taken when a frame analyzer is applied to this problem.

In setting up the SAX analysis, the operator first performs a simple image processing step to discriminate between particles of interest and background. He does this by setting a threshold level on the image analyzer for the SEM signal such that any signal level below threshold is "on background" and any signal level above threshold is "on particle". Under computer control the electron beam is digitally stepped through the field of view in a raster pattern until the signal exceeds the threshold (i.e. until the beam is "on particle"). The digital beam control then guides the beam through preset diagonal and grid patterns that determine the physical dimensions of the particle. The resolution of the raster pattern is dynamically adjusted to suit the size of the particle, up to 4096 by 4096 points to allow small particles to be accurately measured even at low magnification, and yielding a dynamic size range of about 1:500 (the size of the electron beam is approximately 0.6 nm in cross-sectional diameter in a typical analysis).

The primary physical measurements made are area, perimeter, length, and width. From these, various shape descriptors may be derived, along with the coordinates of the geometric center. The computer then directs the electron beam to the center of the particle (or to various proportions of the total particle area), and activates the EDXS for a few seconds to obtain an X-ray energy spectrum. Net X-ray energy counts in pre-designated energy regions that correspond to elements of interest are stored along with X-ray count statistics, physical measurements, coordinates, and any derived parameters, and the system moves on to the next particle in the field until all particles have been analyzed. The final list of characteristics for each particle is termed an "object vector", and this may be treated as a entity for statistical analysis and classification purposes (Karcich et al., 1981; Johnson, 1983). Thus, the technique produces a particle-by-particle description consisting of 30 or more measurements (depending on the number of elements specified), providing a rich data matrix for classification. One mode of classification is by composition. By setting criteria based on the ratios of elemental counts detected in the particle, the system can reliably discriminate among various minerals based on a few seconds of EDXS counts.

Particles were classified by comparing their elemental ratios to a series of criteria. The classification scheme was linear, i.e., as soon as a criterion match was found, the particle was placed in that category without test for any other matches. Criteria were arranged in the classification scheme from most exclusive to most inclusive so as to maximize correct classification.

SAX analysis was performed on an Advanced Research Instruments, Inc. (Boulder, CO) AutoSEM, the only commercially available system using the SAX technology.

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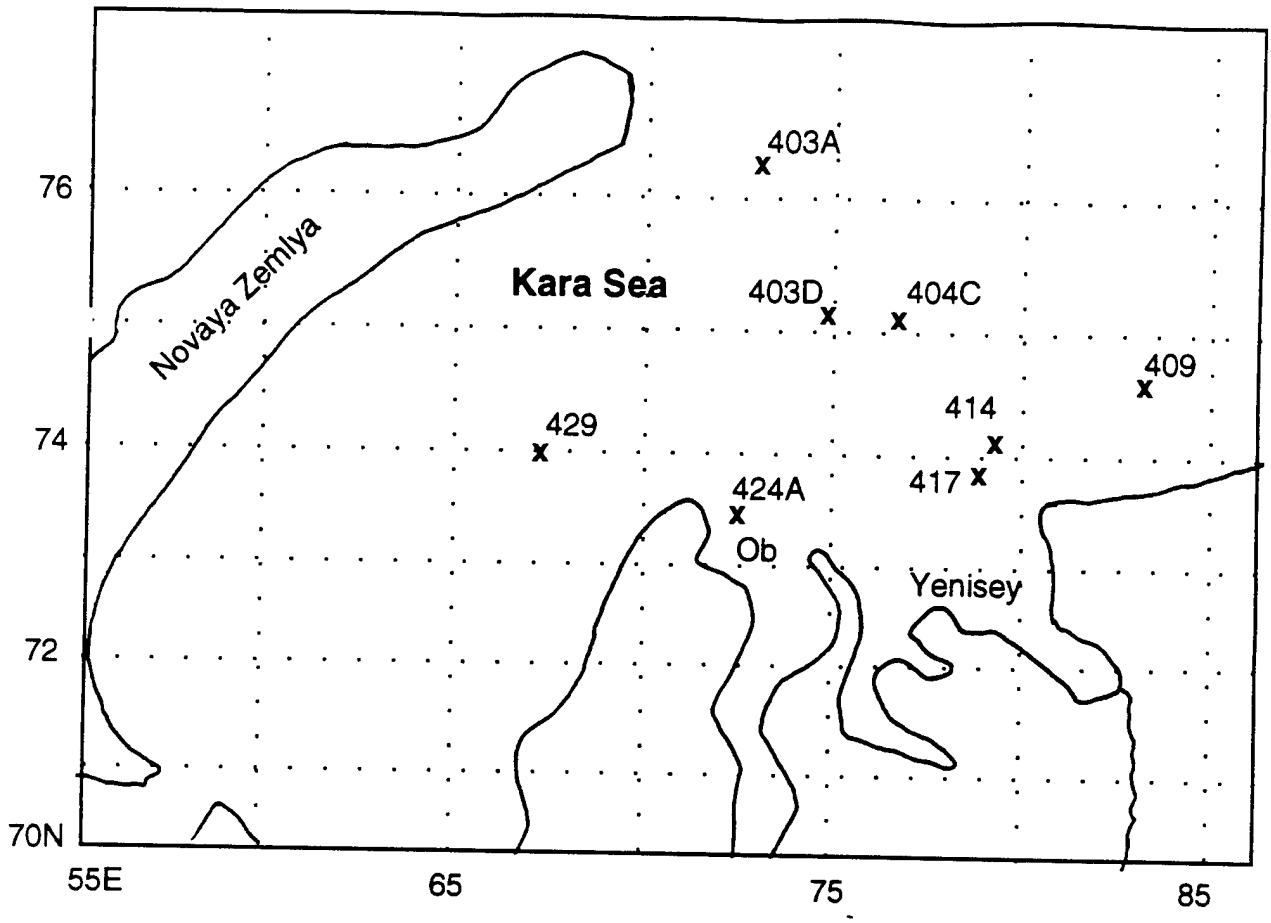


Figure 9.1. Particulate sample locations.

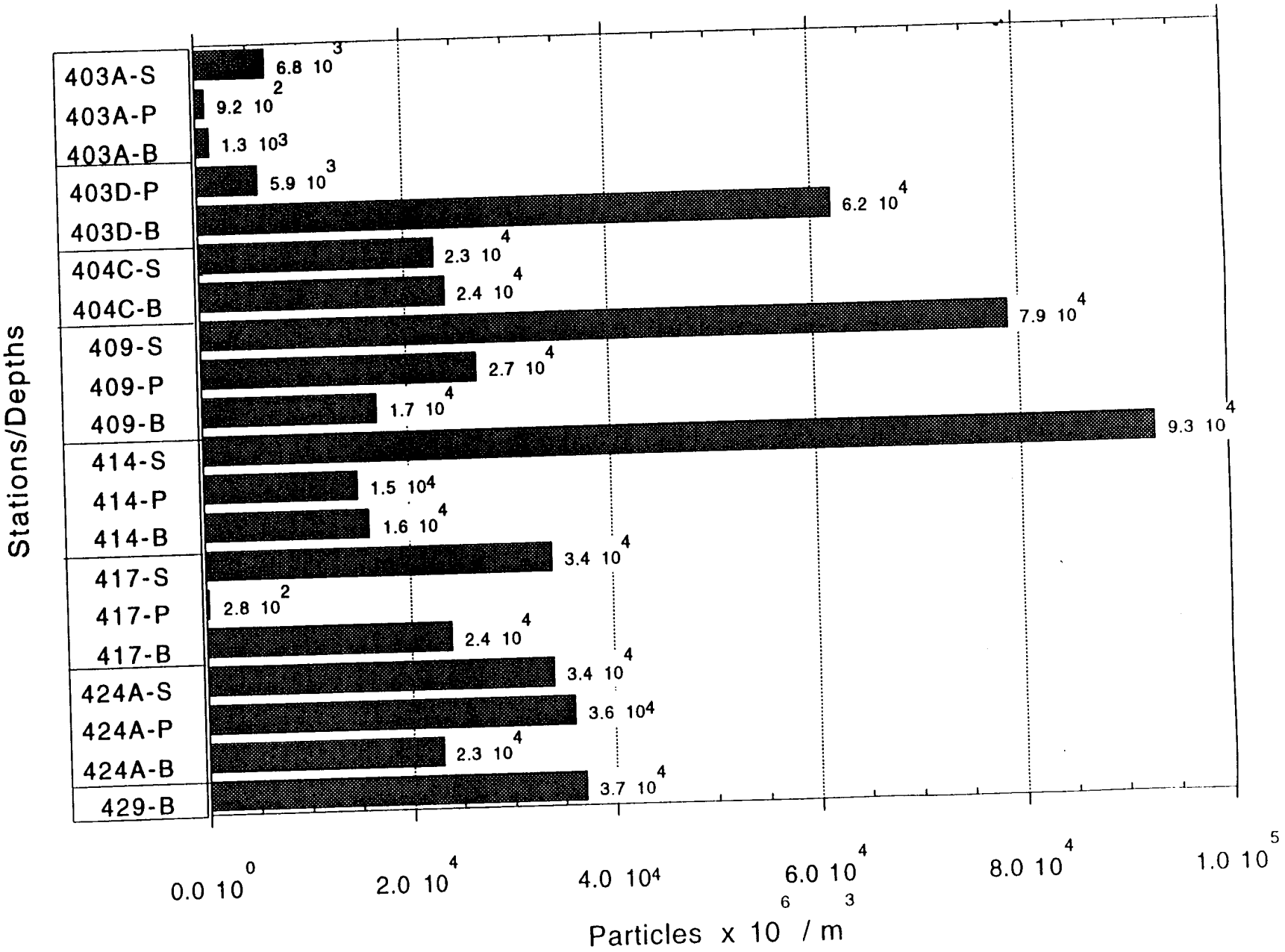


Figure 9.2 Particulate concentrations by station and depth.

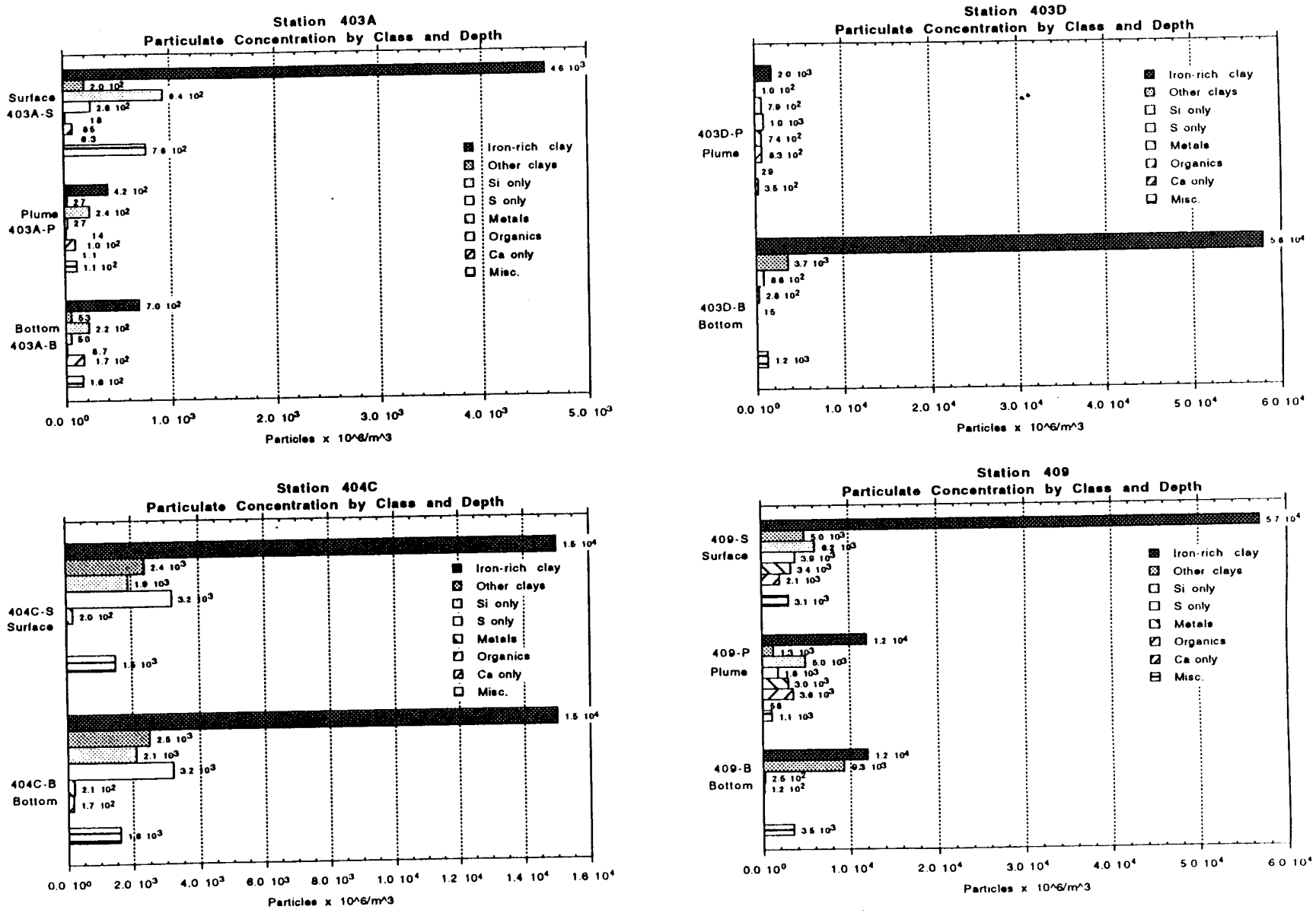
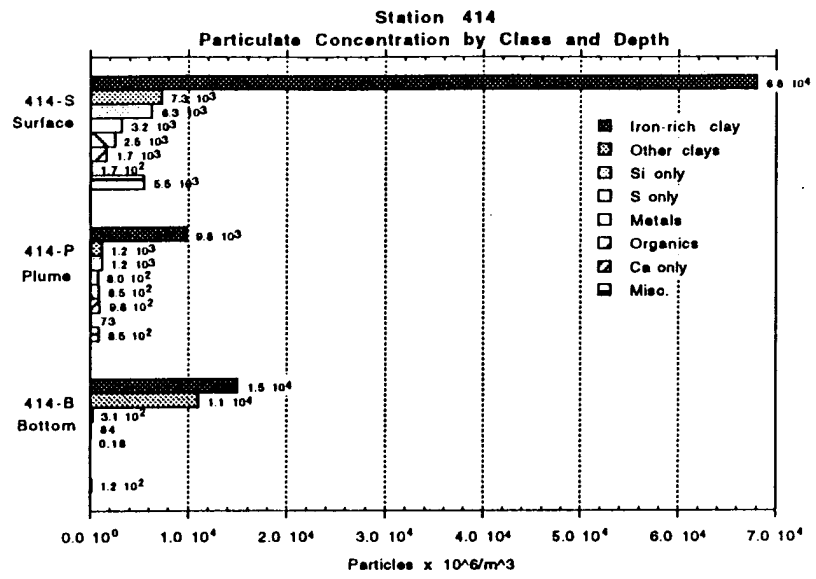
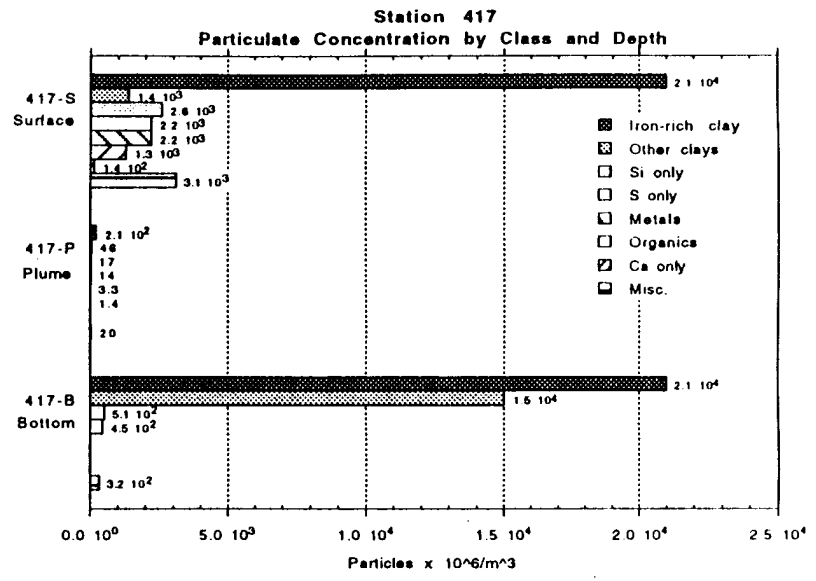
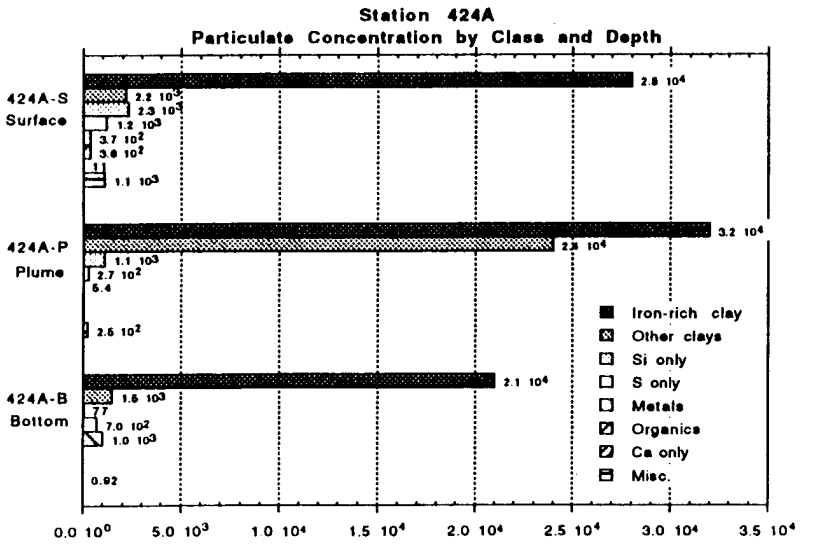


Figure 9.3a-b. Particulate concentrations by mineralogy, depth and station.







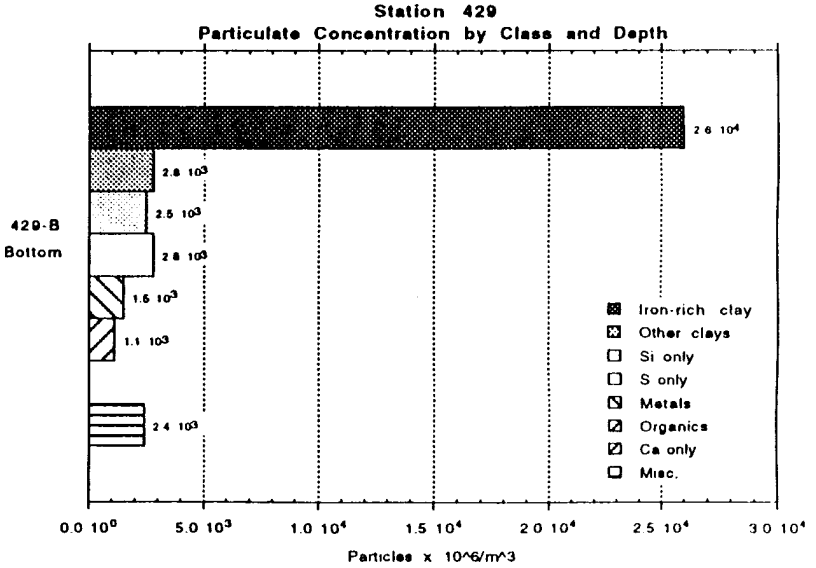


Figure 9.3e-h. Particulate concentrations by mineralogy, depth and station.

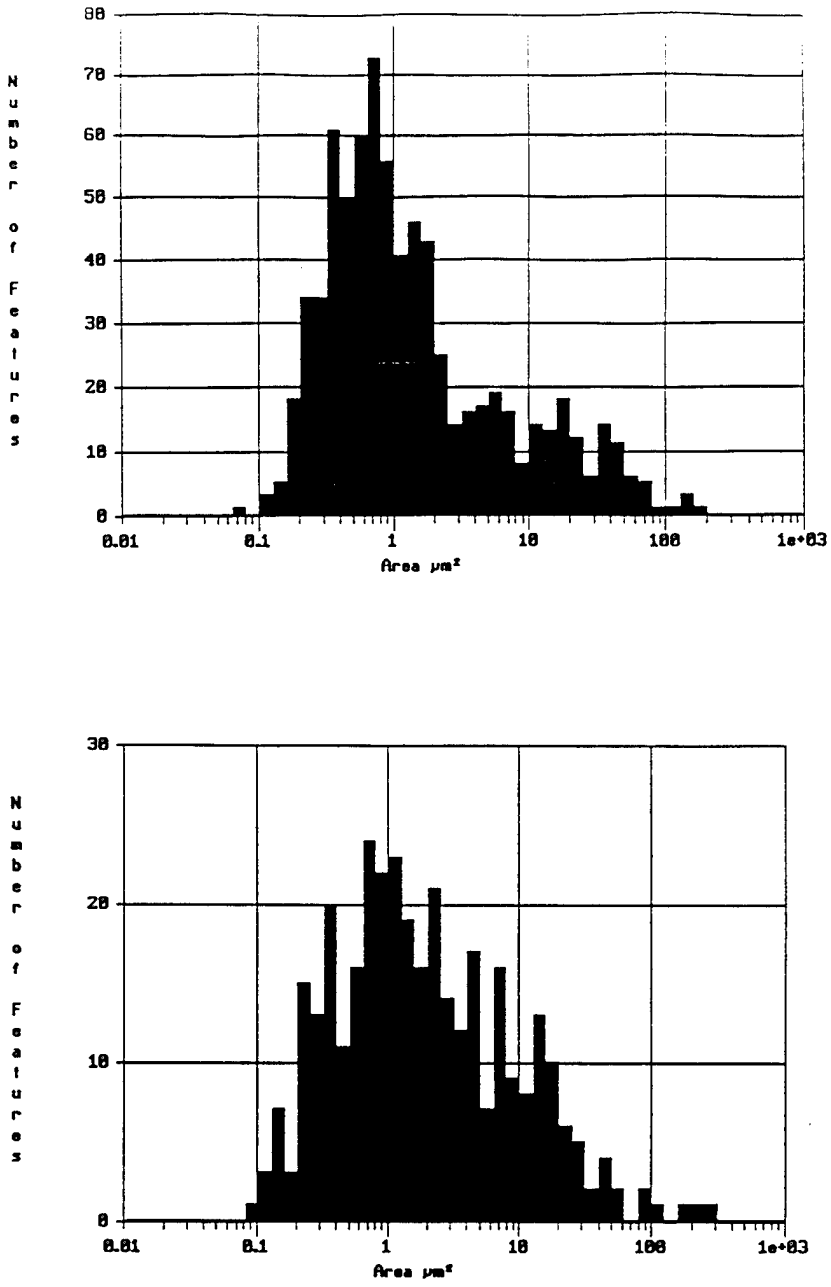


Figure 9.4a,b. Station 403A particle size distributions expressed as number of features analyzed vs. projected area (μm^2) in the surface water (top) and in the plume (bottom.)

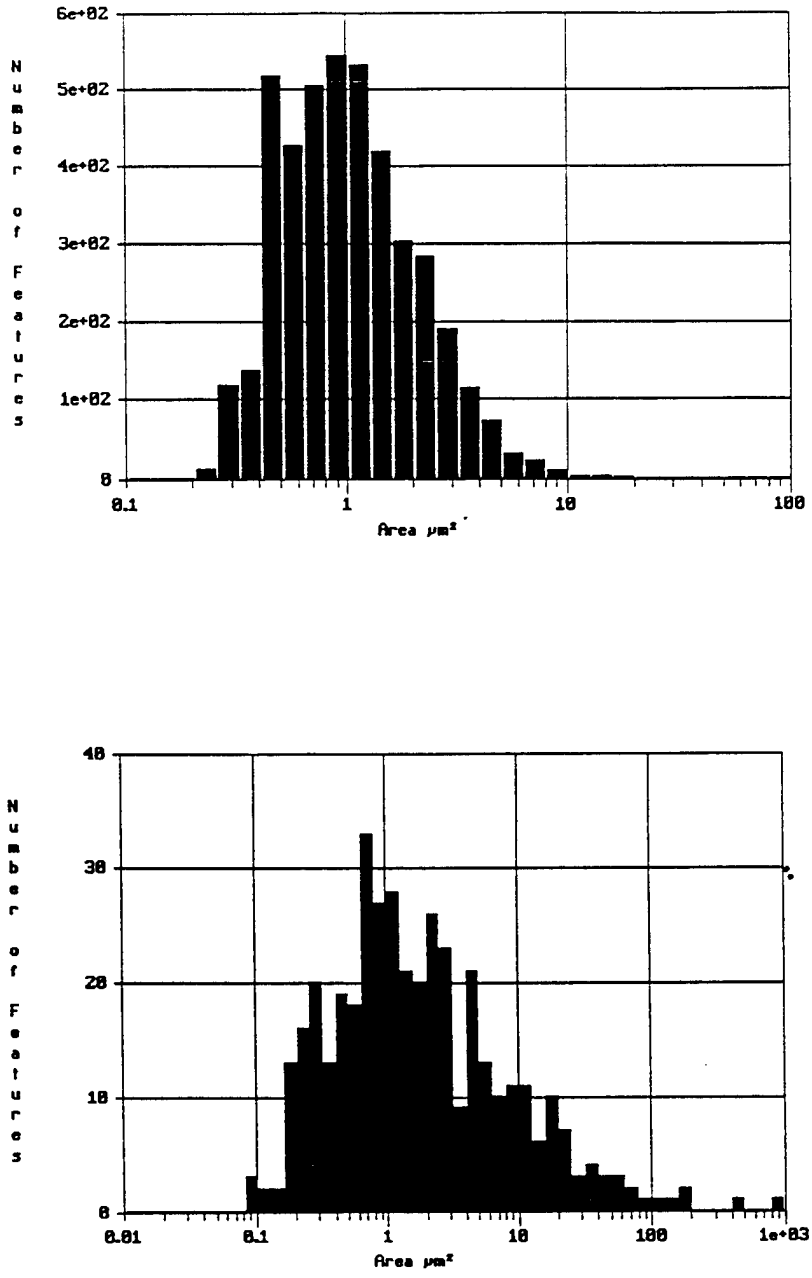


Figure 9.5a,b. Station 403D particle size distributions expressed as number of features analyzed vs. projected area (μm^2) in the plume (top) and in bottom water (bottom.)

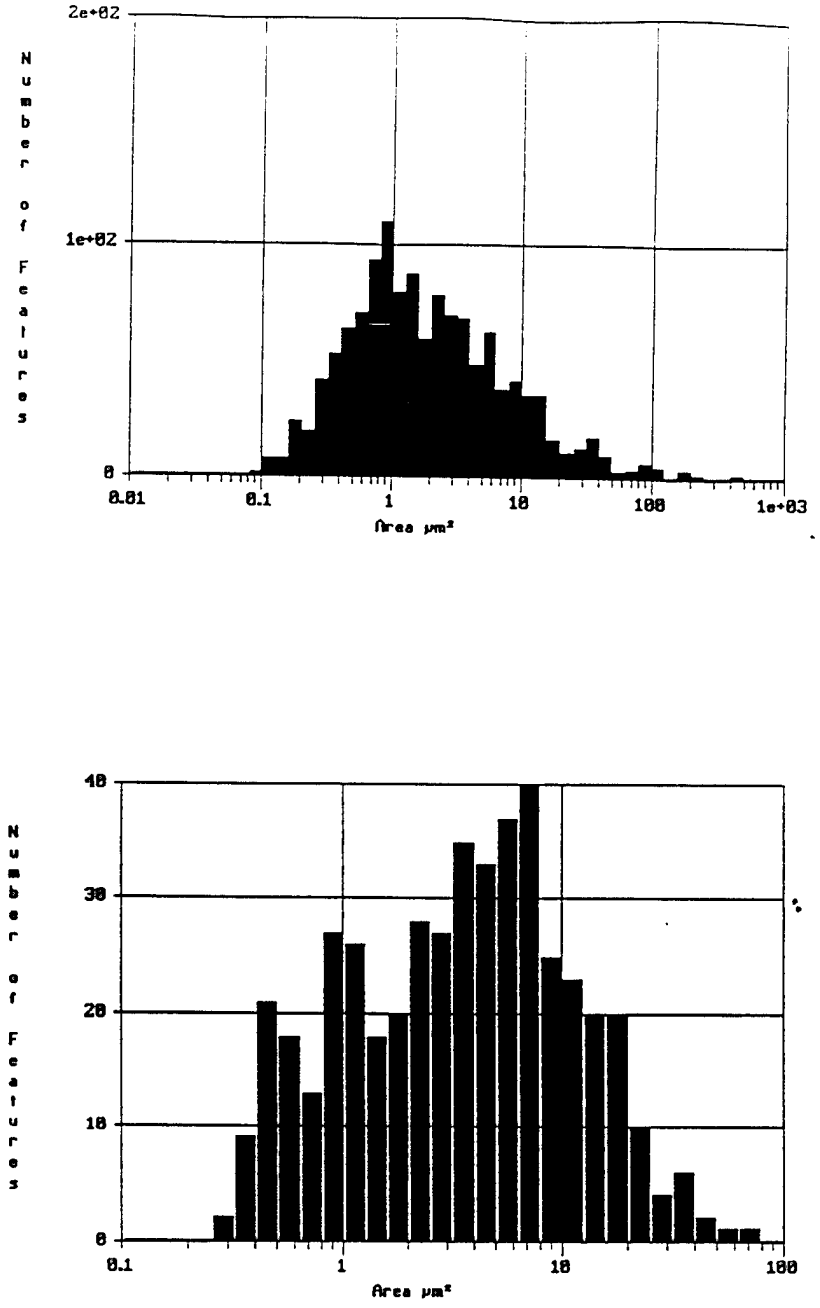


Figure 9.6a,b. Station 403C particle size distributions expressed as number of features analyzed vs. projected area (μm^2) in surface water (top) and in bottom water (bottom.)

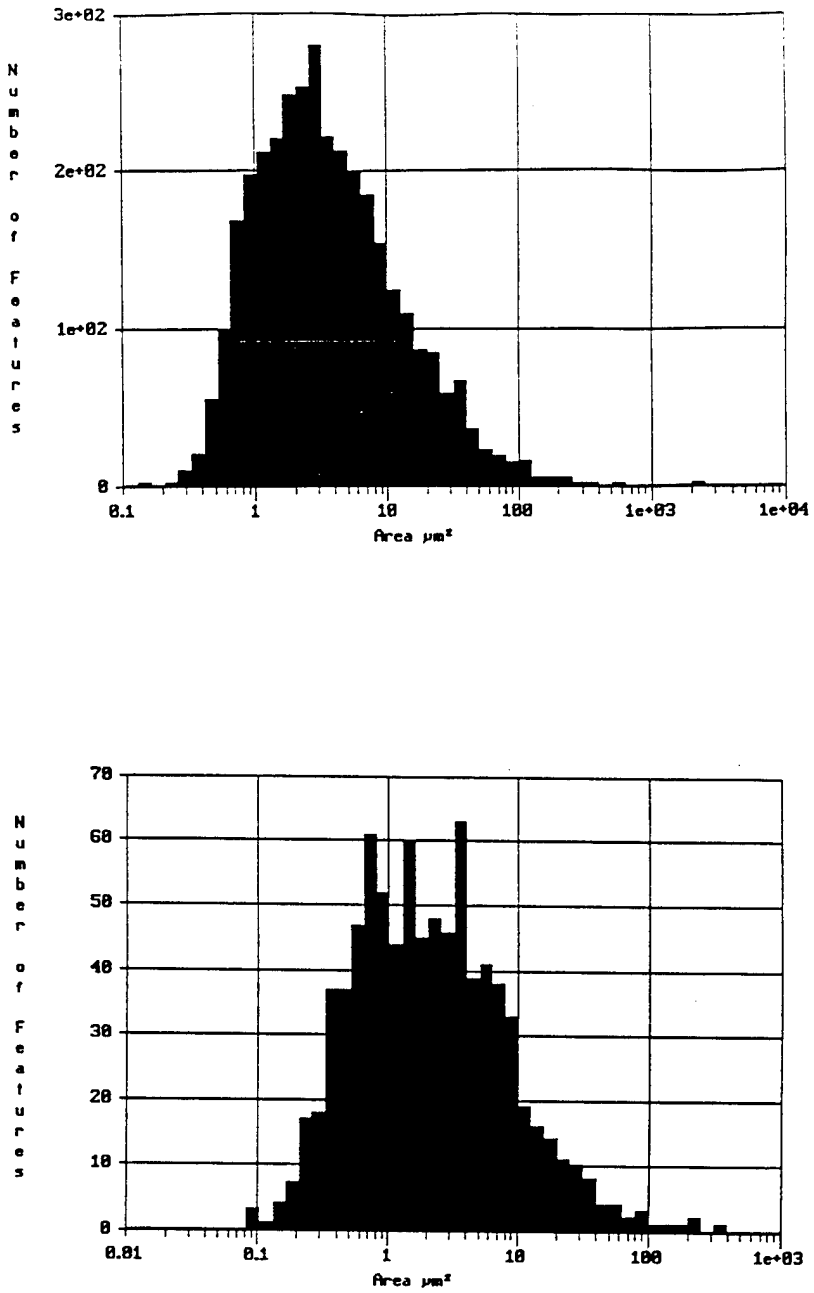


Figure 9.7a,b. Station 414 particle size distributions expressed as number of features analyzed vs. projected area (μm^2) in surface water (top) and in the plume (bottom.)

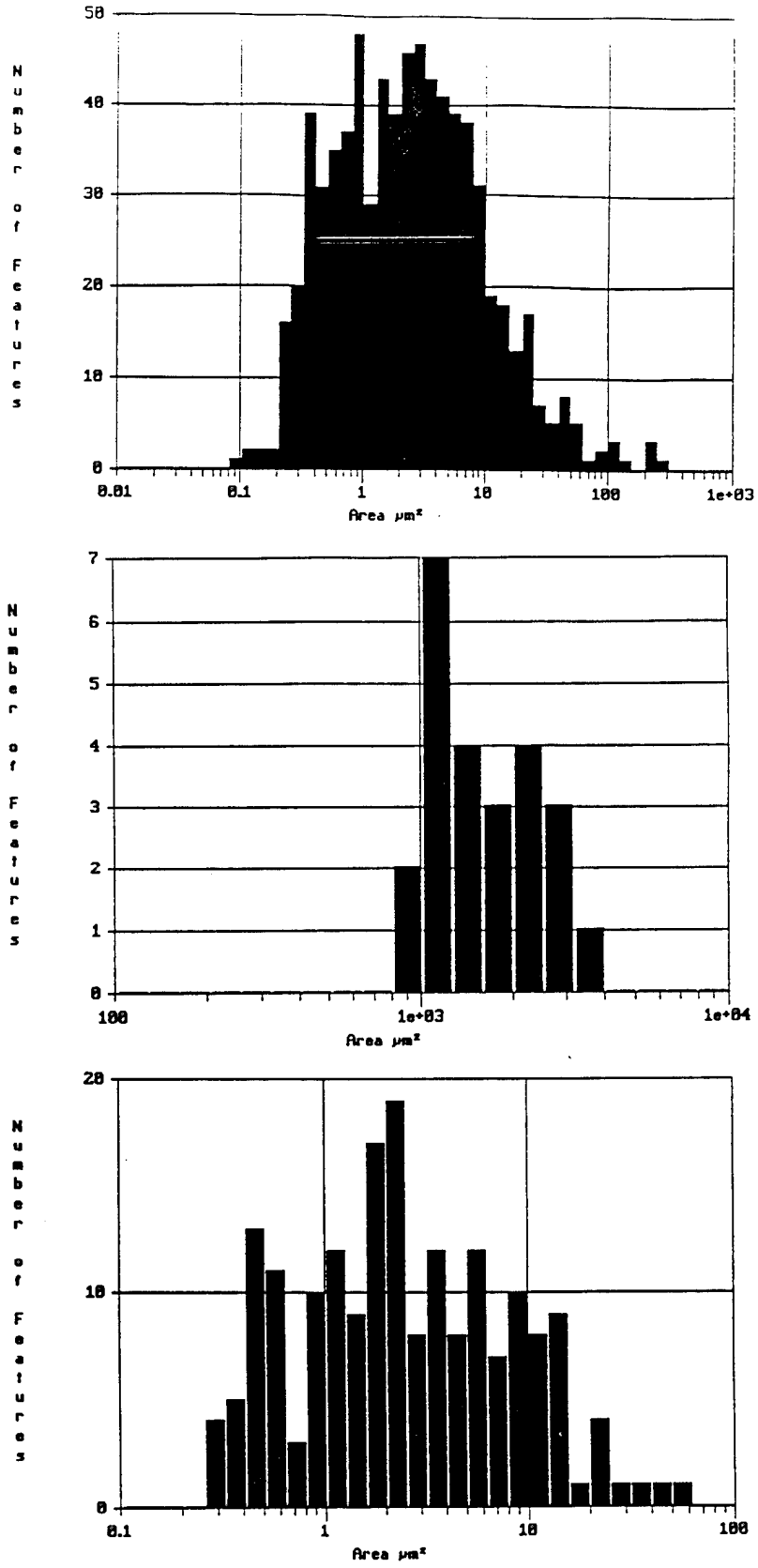


Figure 9.8a-c. Station 417 particle size distributions expressed as number of features analyzed vs. projected area (μm^2) in surface water (top), in the plume (middle) and in bottom water (bottom.)

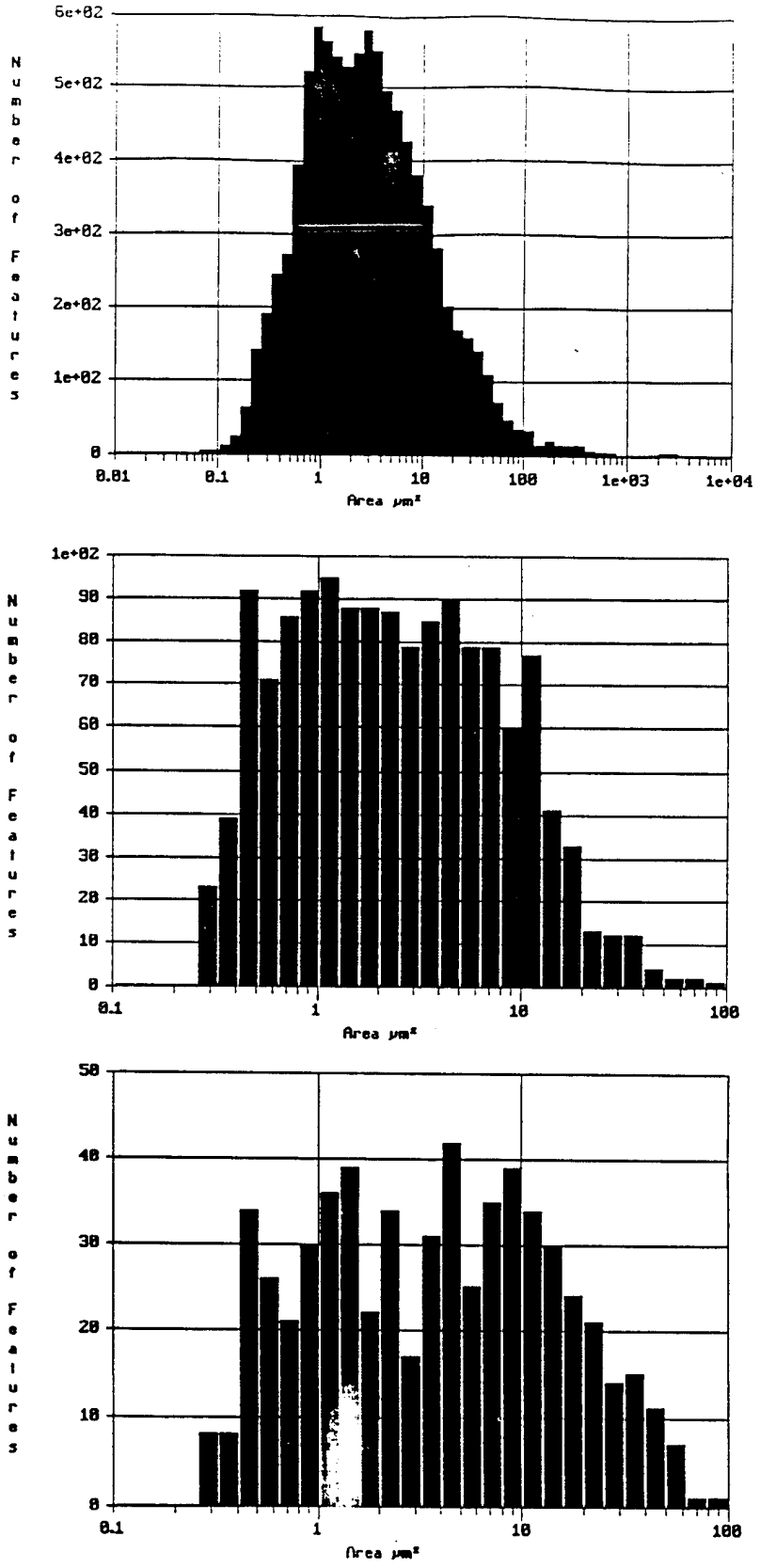


Figure 9.9a-c. Station 424A particle size distributions expressed as number of features analyzed vs. projected area (μm^2) in surface water (top), in the plume (middle) and in bottom water (bottom.)

10. Radionuclide Analysis of 1993 Kara Sea Field Samples

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Progress on this project is reported in a classified addendum.

11. Angara/Yenisey Siberian Rivers Expedition

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I. Narrative Documentation

A. Long term goals

A team of six American scientists from four different US organizations took part in an expedition to Siberia, Russia from July 11 through August 22, 1995. The long-term goal was to investigate and measure both the chemical and radionuclide source terms and potential pathways from land-based sources in the Siberian watersheds of the major river systems which discharge into the Kara Sea. This information will serve as input to the ONR program for modeling the transport of

radionuclides in the Arctic and the assessment of the health risk to US citizens of radioactive pollution in Arctic Seas. The results of this expedition will be included in the NRL geographical information system (GIS) data base of environmental measurements in the Arctic seas and adjacent land masses.

This expedition was sponsored jointly by the Department of Energy Office of Technology Development, DOE/EM-50 and the Department of Defense Office of Naval Research (ONR). The radionuclide analysis was done under ONR funding by scientists from the U.S. Naval Research Laboratory (NRL) and the U.S. Naval Academy (USNA.) DOE funding was used for chemical analysis and for Russian logistic support. DOE supported scientists for this effort from Global Technologies, Incorporated (GTI) and the Idaho National Engineering Laboratory (INEL.) Two Russian research institutes, the Institute of Ecoinformatics Problems (IEP) of the Russian Academy of Natural Sciences (RANS) and the Institute of Radioengineering and Electronics (IREE) of the Russian Academy of Sciences (RAS) were under contract to DOE to provide both technical assistance and logistic support to the American expedition team members.

B. Objectives of this effort

The purpose of the expedition was to perform on-site sampling, characterization, and analysis for environmental pollutants in the Angara/Yenisey river system and adjacent areas. The Yenisey River is one of the major Siberian river systems that empties into the Arctic Sea and is reported to be heavily contaminated by military and industrial activities of the former Soviet Union. Within the Yenisey River system, the Angara River is the major tributary and contributes more than 40% of the water which empties from the Yenisey river into the Kara Sea. The Angara River has several industrial complexes along the way including one of the largest in the entire Russian Federation - the Angarsk Electrochemical and Industrial Complex. In order to understand the impacts to the global ecosystem due to the Yenisey River, it is important to characterize the environmental pollutant source terms from the main river and its major tributaries.

C. Approach

Samples were taken of river bottom sediment, mud from the river banks, and river water. Scientific analysis equipment was transported by air into Russia for on-site analysis of the samples taken during the expedition. A temporary laboratory was setup in the Irkutsk Scientific Center to house the analysis instruments, and samples were brought back to this laboratory for analysis. The importance of the on-site analysis was to allow sites with interesting or unusual findings to be revisited and additional samples obtained, and to assure that the most significant samples were analyzed in case it was not possible to bring samples out of the Russian Federation. Local and regional Russian contacts were essential in carrying out this expedition. These contacts were acquired through the two participating Russian research institutes in order to support the expedition members both in collecting the river sediment and river bank samples and in transporting them back to the temporary laboratory for on-site analysis.

Three types of instruments were used to characterize the collected field environmental samples: 1) a low-background, high-resolution gamma-ray spectrometer for radionuclides, 2) an x-

ray fluorescence spectrometer for heavy metals, and 3) a gas chromatograph for volatile organic compounds.

Radionuclide Analysis. Gamma ray analysis for radionuclides was done with a mechanically cooled, high purity Ge detector. The detector was oriented vertically upward, with the head of the detector protruding into a specially designed cylindrical lead shield that reduced the background counting rate by a factor of about 100. The background counting rate inside the shield was less than two counts per second. Access to the shield cavity for sample changing was via a clam-shell lid.

The detector itself has an integral pre-amplifier. All power supplies and electronics, consisting of an amplifier, analog to digital converter (ADC) and multi-channel analyzer, were contained on plug in cards inside a 66 MHZ 486 personal computer. The data were collected in 4096 channel spectra for an average collection time of 24 hours, though this can vary widely depending on signal strength and desired statistical accuracy. Gamma-ray spectra were collected with an energy spectrum ranging from 40 keV to 3 MeV. Special purpose computer software provided on-line spectral display, peak analysis, radionuclide identification and calculation of activities for radionuclides whose gamma-rays were detected. The average energy resolution obtained was about 2 keV at the 662 keV gamma-ray line from decay of ^{137}Cs. The gamma ray detection efficiency was 2.3% at the 662 keV ^{137}Cs line. The efficiency calibrations were done using NIST standard sediment samples and specifically designed NIST traceable calibration standards manufactured by Northern Scientific Company for this detector system. To obtain a sufficiently sensitive efficiency calibration, the detectors had to have calibrations that were dependent on both gamma-ray energy and sample mass. Energy calibrations were done on the detector at NRL prior to shipping to the field and were then checked with a thorium lantern mantel in the field.

A background spectrum was taken of the empty cave for thirty-one hours. Analysis for individual gamma ray lines in a sediment sample spectrum was done by first subtracting the live-time corrected background counts from the counts for each peak in the sample spectrum. For each gamma-ray line the activity of the decaying radionuclide was then calculated using the calibrated detector efficiencies and a library of gamma-ray energies, branching ratios, and lifetimes. In order to be consistent, all activities were decay corrected to a collection date of August 1, 1995. We could detect a level of ^{137}Cs as low as 5 Bq/kg in 24 hours.

Chemical Analysis. Analyses for volatile organic compounds (VOCs) were done using a gas chromatograph supplied and operated by INEL. Heavy metal analysis was also performed by INEL using an x-ray fluorescence analyzer.

D. Accomplishments

The expedition began near the source of the Angara river at Lake Baikal near the Siberian city of Irkutsk. Lake Baikal is the deepest fresh water lake in the world and contains more than 20% of the global fresh water supply. It has more than 300 inlets and only one outlet —the Angara River. We proceeded along the Angara, sampling at selected sites of interest downstream to the junction with the Yenisey river, including the vicinity of Irkutsk, near the nuclear and petrochemical complexes at Angarsk, and the industrial complex at Bratsk. At the junction, the expedition was extended into

the Yenisey River in both directions— ~50 km downstream to the north and ~70 km upstream to the south. At one point the expedition party was on the Yenisey River only about 250 km north of the nuclear complex at Krasnoyarsk. This city is reputed to have contributed the majority of the radionuclide contamination in the Yenisey River. The expedition covered a total distance of more than 1500 km. Figures 11.1-3 show maps of the regions of Irkutsk/Angarsk, Bratsk, and the Angara/Yenisey junction with the sampling sites indicated by stars.

Local boats were chartered at preselected locations along the Angara River to collect river sediment samples using a gravity corer. Rental cars were also used to transport team members to cities and facilities along the Angara River to collect hand packed core samples along river banks and drainage channels. A domestic air carrier was used to transport expedition team members and their equipment to the city of Bratsk for sampling above and below the Bratsk hydroelectric dam. A rental helicopter was used to transport the expedition team to the Angara/Yenisey River junction (no commercial air carrier was available) to collect river sediment and riverbank samples. A total of seventy samples were collected and documented including an 80-kg sample from directly below the Irkutsk dam near the Irkutsk Scientific Center. More than forty of these samples were prepared and analyzed on-site.

Table 11.1 shows the complete inventory of samples collected and Table 11.2 gives the results for those samples that were analyzed in the field. Priority for field analysis was given to: 1) a representative sample from every site, 2) those samples from sites of particular interest, and 3) analysis of samples from sites that were revisited as prompted by interesting or unusual analysis results. Time limitations determined how many samples could be analyzed in the field. All samples were shipped back for further analysis.

Three types of samples were collected: river sediment samples, river bank sediment samples, and water samples. Whenever a sample was obtained, the location was marked using a hand held Garmin global positioning system (GPS-45) which was generally accurate to within thirty meters.

River Sediment Samples. These samples were taken from a small boat in the areas of interest. The Angara is a very rocky river and places for good sediment samples were difficult to locate. In general, we had to find places on the river that were out of the main current and relatively still. Small islands and inlets seemed to provide the best sediment. The Yenisey river was more conducive to sediment sampling in the region upriver of the Angara - Yenisey junction, but the same general sampling scheme still applied. After the Angara - Yenisey junction, the Yenisey was essentially identical in nature to the Angara river.

The samples were obtained using a 40 kg Phleger gravity corer. This device is shaped like an aerial gravity bomb with a stainless steel coring tube attached to the nose. The Angara's rocky bottom damaged the stainless steel coring tube on numerous occasions. Fortunately, we had a number of spare coring tubes with us that allowed us to repair the corer and continue sampling.

Sediment samples from the 1.5 inch diameter tubes were counted in the field. The first six centimeters of sediment from each core were used, as this was felt to be an accurate representation of the surface sediment. This sample was first dried in an oven at ninety degrees centigrade—avoiding any boiling—to remove the water. The dried samples were then sieved to remove rocks and other debris, and put in small plastic bags for analysis. The samples analyzed ranged from about ten to sixty grams, depending largely on the sediment type and the amount of debris removed.

River Bank Sediment Samples. These cores were taken by hand; one simply pushed a plastic coring tube into the sediment at the river's bank, dug underneath the tube, capped it off, then pulled it out. We took samples of 1.5 and 3 inch diameters. The 1.5 inch were taken using the plastic core liners that were used with the Phleger corer. These were taken in areas where it wasn't feasible to use the Phleger corer in the river or at locations where we had no boat available. The three inch cores were taken with plastic tubes that were sharpened on one end to make coring easier. These were taken sporadically to give us larger samples that could be sliced into layers for possible depth profiling, and also to collect samples for NRL Stennis to use for chemical analysis.

In one case, analysis of previously taken river and river bank sediments identified a particular location as very interesting. We returned to this location and shoveled up about 40 kg of sediment from the river bank to be taken back to the US for possible isotopic separation.

Water Samples. No water samples were taken for radionuclear analysis, since this in general involves very large volumes of water (e.g. about 1000 liters for ^{137}Cs analysis) which we were not set up to collect or filter. Instead, small bottles of water were collected sporadically to be used for chemical analysis. Also, chemical analysis was performed on the supernatant water that was serendipitously collected as part of the Phleger corer operation.

E. Results

Radionuclides. All measurements were performed on the first 6 cm of the cores. Not all samples collected have been analyzed since it requires about 24 hours for each analysis. The preliminary results summarized below refer to samples analyzed on site and could change when a complete analysis of all samples brought back is performed in the laboratory. For comparison, worldwide background levels of ^{137}Cs range from 0 to 10 Bq/kg.

- Other than naturally occurring radioisotopes, only ^{137}Cs isotopes were detected in all samples analyzed from above the Irkutsk dam. Activities of ^{137}Cs were detected at or near background levels and ranged from 2 to 12 Bq/kg of river sediment (dry weight.)

- The ^{137}Cs isotope activities in all samples analyzed from below the Irkutsk dam ranged between <4 and 30 Bq/kg of river sediment (dry weight).

- Only background levels of ^{137}Cs activity were detected from samples analyzed from the Bratsk expedition.

- In the Angara River upstream of the Yenisey/Angara junction, the ^{137}Cs activities from the samples analyzed were at background levels, ~2 Bq/kg of river sediment (dry weight).

- In the Yenisey River downstream of the Yenisey/Angara River junction, the ^{137}Cs activities from the samples analyzed ranged from 3 to 27 Bq/kg of river sediment (dry weight). The latter is 10-15 times the activity levels detected on the Angara river upstream of the junction.

- In the Yenisey River upstream of the Yenisey/Angara River junction, significantly higher than background levels of mixed reactor products were detected in the samples analyzed: ^{60}Co ranged from 9 to 240 Bq/kg of river sediment (dry weight), ^{137}Cs from 14 to 400 Bq/kg of river sediment (dry weight) and ^{152}Eu from 7 to 150 Bq/kg of river sediment (dry weight).

- These readings showed wide variations depending on sampling location. Highest values were in a still backwater, in mud from a flood plane, and at the tip of a small island near the river junction, places out of the main current where sediment is most likely to settle out from suspended particulates in the water.

- The high radioisotopic activity observed in sediment cores from the Yenisey river above the junction with the Angara are indications either of reactor products (^{137}Cs, ^{152}Eu) or of neutron activation (^{60}Co) and thus are consistent with releases from the production reactors at Krasnoyarsk ~250-300 km upstream on the Yenisey.

- The relatively short halflife of ^{60}Co (5 years) indicates that the releases were probably fairly recent.

- Samples collected from directly below the Irkutsk dam near the cement plant indicated unusually high concentrations of both ^{235}U and ^{238}U activities. The activity levels were detected in both hand packed and gravity core samples. These samples were collected on two different days.

- The ^{235}U isotope activities range from 10.8 to 26.0 Bq/kg of river sediment (dry weight) and the ^{238}U activities are between 280 and 660 Bq/kg of river sediment (dry weight). This implies a relative ^{235}U concentration of $0.6 \pm 0.2\%$ which is consistent with its natural abundance of 0.7%.

- The potential source(s) of the ^{235}U and ^{238}U observed from samples collected directly below the Irkutsk dam is unknown at this time.

Gamma-Ray Spectra. Attached are three gamma-ray spectra of interest taken of sediment samples during the expedition.

- IRK72707 (Figure 11.4) shows a gamma-ray spectrum from a sample taken above the dam at Irkutsk. The weak 662 keV line from ^{137}Cs is in the low worldwide background range with an activity of 2 Bq/kg (dry weight). The unlabeled gamma-rays in the picture are all due to naturally occurring radioactivity.

- IRK81601 (Figure 11.5) shows a gamma-ray spectrum from a sample taken just below the dam at Irkutsk. The spectrum shows strong gamma-rays from ^{235}U at 143 keV and 186 keV with an activity of 26 Bq/kg (dry weight). Also shown are gamma rays from two short-lived daughters of ^{238}U in the decay chain $^{238}U \rightarrow {}^{234}Th \rightarrow {}^{234m}Pa \rightarrow {}^{234}U$: the 1001 keV gamma-ray from ^{234m}Pa with an activity of 660 Bq/kg (dry weight) assuming equilibrium with ^{238}U; and the 63.3 keV and 92.3, 92.8 keV unresolved doublet of gamma rays from ^{234}Th whose activity is uncertain since the detector has not yet been calibrated accurately for low energy gamma rays.

- IRK80707 (Figure 11.6) shows a gamma-ray spectrum from a sample taken in a backwater of the Yenisey river above the junction with the Angara. This spectrum shows strong reactor product gamma rays from ^{137}Cs at 662 keV and multiple lines from ^{152}Eu. It also shows strong lines at 1173 and 1332 keV from ^{60}Co which is produced by neutron activation of stainless steel. These are clear indications that this gamma-ray activity comes from releases from the production reactor at Krasnoyarsk.

Heavy Metals

- Heavy Metals were present in all river bank and river sediment samples collected to date throughout the entire Angara River system.

- Four major Heavy Metal groups were identified in all samples. They are As, Hg, Cr, and Pb. Their concentration levels in the Angara River samples ranged as follows:

As	Hg	Cr	Pb
30 ppm - 103 ppm	<100 ppm-600 ppm	50 ppm-530 ppm	<1 ppm-430 ppm

- Other heavy metals also were present in all the collected samples. Detailed analyses are expected to be performed to identity and to determine their identities and concentration levels.

Volatile Organic Compounds (VOCs)

- Several known and unknown VOCs were detected throughout the entire Angara River except at locations immediately below hydroelectric dams.

- Toluene was detected in almost all collected Angara River water samples. Past experiences demonstrate that Toluene is a surrogate compound indicating the presence of gasoline and/or diesel products. The source location(s) of Toluene is difficult to pinpoint at this time without a detailed measurement program and the collaboration of the Russian oblast government. The Toluene concentration levels from all collected Angara samples varied from <0.01 ppm to 0.03 ppm.

- M-Xylene, Toluene, and several unknown VOCs were detected near most major industrial cities along the Angara River especially near and downstream of the city of Angarsk. The

Angarsk Electrochemical and Industrial Complex, located on the west bank of the Angara River ~30 km northwest of Irkutsk, is one of the largest industrial complexes in the Russian Federation. The presence of M-Xylene, Toluene, and other VOCs near and downstream of Angarsk is an indication of pollutants released from the Angarsk industrial complex either accidentally or through unregulated environmental practices. The M-Xylene concentration levels varied from 0.04 ppm to 0.15 ppm. The identifications and concentration levels of the unknown VOCs have not been determined at this time.

- Very low concentration levels of Toluene were detected in all Angara River samples collected between the helicopter landing site ~70 km upstream and the Yenisey/Angara river junction at Strelka. Strelka is a light industrial and timber-processing town located right at the junction. The concentration levels were at the minimum detectable limits of the GC instrument we took on the expedition.

- Only one VOC was detected in the Yenisey River from all the locations sampled and analyzed starting ~70 km upstream of the Yenisey/Angara river junction and ending ~50 km downstream of the junction. The source of this VOC is probably from Krasnoyarsk, which is located ~300 km upstream of the Yenisey/Angara river junction. Preliminary assessment of the retention time indicated that Methylene Chloride is the likely candidate of this unknown VOC. Its concentration levels ranged between 0.01 ppm and 0.02 ppm.

F. Impact for Science or Systems Applications

This expedition has provided the first measurements by US scientists (in collaboration with Russian institutes) of radionuclide and chemical pollutants in the important Angara/Yenisey River system which drains a large portion of the Siberian industrial heartland and empties into the Kara sea. We have shown that reactor products (likely from the Krasnoyarsk complexes) are transported downstream by the Yenisey river in significant quantities, with levels as high as 500 Bq/kg of ^{137}Cs observed near the junction with the Angara over 200 km downriver from Krasnoyarsk. On the other hand, much lower levels were observed on the Angara and these were localized in the Irkutsk/Angarsk industrial region. This supports the assumption that Krasnoyarsk is the source of the relatively high levels of ^{137}Cs (50-70 Bq/kg) that have been observed in the Yenisey estuary where it empties into the Kara sea.

G. Transitions Expected.

This expedition marks the beginning in the characterization of the land based source terms of radionuclides and chemical pollution in the Siberian river systems which drain into the Arctic seas. The following are specific recommendations for extending this characterization, building on the experiences and results from this expedition.

- Continue to pursue reactor products and chemical pollutants measurements in a comprehensive survey of the Yenisey River from Krasnoyarsk downstream to meet up with the regions in the estuary of the Yenisey which have been studied by ONR sponsored expeditions entering from the Kara Sea.

- Repeat sampling expeditions and measurements below the Irkutsk dam near the cement plant to map out the extent of the ^{235}U and ^{238}U and to comprehend the origins and pathways of the uranium isotopes.

- Initiate similar studies and environmental expeditions to other Siberian river systems and their tributaries in order to understand the source terms of the VOCs, Heavy Metals, Radionuclides, and other pollutants from the former Soviet Union and current Russian industrial and military facilities. These will include the Ob River to the west and the Lena River to the east of the Angara/Yenisey River system.

- Perform detailed analyses with the collected samples, specifically samples from directly below the Irkutsk dam to determine the chemical compositions and associated molecular structures of both ^{235}U and ^{238}U isotopes.

- Analyze samples collected upstream of the Yenisey/Angara river junction to determine the chemical compositions of the reactor products and related chemicals.

- Perform analyses on the collected samples to determine the concentration of Plutonium isotopes.

- Initiate a program with existing Russian organizations and institutes to retrieve historic and archived ecological data to better understand the magnitude of the environmental pollution problems in the Siberian ecosystem.

- Investigate the possibilities to setup and place mobile and fixed field laboratories in Siberia for future expeditions.

H. Relationship to Other Projects.

The experiences of this expedition will serve to provide input and support to the DOE Office of Technology Development and its International Programs Office in working with the Russian scientists and institutes.

I. Application to the Arctic Radioactive Waste Assessment Problem.

This information will serve as input to the ONR program for modeling the transport of radionuclides in the Arctic and the assessment of the health risk to US citizens of radioactive pollution in Arctic Seas. The results of this expedition will be included in the NRL geographical information system (GIS) data base of environmental measurements in the Arctic seas and adjacent land masses.

II. Statistical Information

A. List of Publications

None as yet.

B. Number of Graduate Students

None.

C. Patents

None.

D. Presentations

No formal presentations as yet.

E. Committed Service

None.

F. Awards

None.

G. Russian Participation

The Russian institutes contributed 30% of the work on logistics support and sample collection. No support by ONR ANWAP (Russian support came from DOE/EM-50.)

Table 11.1. Sampling Locations

Angara/Yenisey Siberian Rivers Expedition 1995					
Sampling Log					
date	*location*	*sample ID*	*Latitude*	*Longitude*	*Type of*
			(deg. N)	*(deg. E)*	*Sample*
26-Jul-95	Angara at Big River	IRK72601	51.90780	104.80496	gravity core
27-Jul-95	Angara above Irkutsk dam	IRK72701	52.17005	104.38341	hand core
	left bank	IRK72702	52.16422	104.39479	gravity core
	"	IRK72703	52.17878	104.39429	gravity core
	right bank mud flats	IRK72704	52.18856	104.43600	gravity core
	"	IRK72705	52.18868	104.43675	hand core
	"	IRK72706	52.20934	104.40891	hand core
	"	IRK72707	52.20930	104.40797	gravity core
28-Jul-95	Angara below Irkutsk dam,	IRK72801	52.25112	104.29539	gravity core
	near cement plant	IRK72802	52.25025	104.29503	hand core
	Angara below Irkutsk dam,	IRK72803	52.36339	104.25925	gravity core
	near downstream islands	IRK72804	52.37386	104.23533	hand core
29-Jul-95	Stream near Savvateevka	ANG72901	52.32782	103.62660	hand core
	Kitoy river	ANG72902	52.44318	103.64592	hand core
	"	ANG72903	52.48834	103.79563	hand core
	"	ANG72904	52.55293	103.86769	hand core
	Technical ditch 1	ANG72905	52.50478	103.93449	hand core
	Technical ditch 2	ANG72906	52.48263	103.95505	hand core
30-Jul-95	Angara above Angarsk	ANG73001	52.46057	104.06700	gravity core
	"	ANG73002	52.48875	104.06291	gravity core
	"	ANG73003	52.50669	103.96363	gravity core
	(outlet of ditch 1)	ANG73004	52.50622	103.95530	gravity core
	Angara at Angarsk	ANG73005	52.54943	103.96879	gravity core
	left channel	ANG73006	52.58340	103.94976	water sample
31-Jul-95	Kitoy river	KIT73102	52.46803	103.76039	hand core
	"	KIT73103	52.51720	103.81370	hand core
	"	KIT73104	52.60522	103.86269	gravity core
5-Aug-95	Angara near Kulakovo	KUL80501	58.13490	93.61829	gravity core
	above junction with	KUL80502	58.14533	93.61829	water sample
	Yenisey	KUL80503	58.14652	93.58801	gravity core
6-Aug-95	Angara above Strelka	STR80601	58.14851	93.25640	gravity core
	"	STR80602	58.07381	93.12322	water sample
	Yenisey at junction	STR80603	58.09724	92.99269	gravity core
	Beach at Lesosibirsk	STR80604	58.18642	92.53726	small hand core
	below Leso. right bank	STR80605	58.24949	92.52090	gravity core
	downstream right bank	STR80606	58.30259	92.43286	gravity core

Table 11.1 (cont.) Sampling Locations

date	location	sample ID	Latitude (deg. N)	Longitude (deg. E)	Type of Sample
7-Aug-95	Yenisey above junction	YEN80701	57.75829	93.26824	small hand core
	near Kazachinskoye	YEN80702	57.75803	93.26075	small hand core
	left bank	YEN80703	57.75818	93.26038	hand core
	right bank	YEN80704	57.78082	93.29126	gravity core
	right bank side channel	YEN80705	57.78322	93.29894	gravity core
	left bank side channel	YEN80706	57.86512	93.23798	small hand core
	right bank backwater	YEN80707	57.91635	93.19787	gravity core
8-Aug-95	Yenisey flood plane	YEN80801	58.01997	93.14856	small hand core
12-Aug-95	Irkutsk below dam	IRK81201	52.24338	104.29232	small hand core
14-Aug-95	Bratsk above dam	BRA81401	56.22039	101.68307	gravity core
	left bank near museum	BRA81402	56.21691	101.68354	gravity core
	left bank further north	BRA81403	56.23552	101.67945	gravity core
	right bank opp. Bratsk	BRA81404	56.14171	101.79566	gravity core
	left bank near monument	BRA81405	56.15024	101.66231	gravity core
	entrance to harbor	BRA81406	56.13535	103.62660	gravity core
	off bauxite plant	BRA81407	56.13382	103.64592	gravity core
	north shore	BRA81408	56.20086	103.79563	hand core
	pioneer camp	BRA81409	56.21119	103.86769	hand core
15-Aug-95	Bratsk below dam	DAM81501	56.31200	103.93449	gravity core
	right bank	DAM81502	56.31643	103.95505	gravity core
	tip of peninsula	DAM81503	56.33675	101.85541	gravity core
	right bank inlet	DAM81504	56.31414	101.87775	gravity core
	left bank	DAM81505	56.38282	101.86474	gravity core
	left bank side channel	DAM81506	56.38086	101.83616	gravity core
	upstream of bridge	DAM81507	56.33313	101.80834	gravity core
	left bank backwater	DAM81508	56.30632	101.81044	hand core
16-Aug-95	Irkutsk below dam	IRK81601	near IRK81201		small hand core
	"	IRK81602	near IRK81201		small hand core
	"	IRK81603	near IRK81201		small hand core
17-Aug-95	Angarsk above Kitoy jnc.	ANG81701	52.62104	103.94467	water sample
	Angarsk below Kitoy jnc.	ANG81702	52.69984	103.72951	small hand core
	near village Telma	ANG81703	52.70778	103.71559	small hand core
	Irkutsk below dam	IRK81704	52.24722	104.29056	5 gallon sample

Table 11.2. Preliminary Results of Gamma-ray Analysis

Angara/Yenisey Siberian Rivers Expedition 1995 -- Preliminary Results								
High Resolution Gamma-Ray Measurements of Surface Sediment								
Gary W. Phillips and Robert A. August, U.S. Naval Research Laboratory								
Mark J. Harper, U.S. Naval Academy								
Irkutsk, Siberia, Russian Federation, August 18, 1995								
				Weighted Average Isotopic Activity [Bq/kg]#				
General Area	*Sample*	*Lat.(N deg.)*	*Long.(E deg.)*	*137Cs*	*60Co*	*152Eu*	*235U*	*238U*
Irkutsk - above the dam	IRK72704	52.18856	104.43600	11.8 +/- 1.2	nd	nd	nd	nd
	IRK72707	52.20930	104.40797	2.2 +/- 1.0	nd	nd	nd	nd
Irkutsk - below the dam	IRK72801	52.25112	104.29539	31.1 +/- 1.4	nd	nd	10.8 +/- 2.6	280 +/- 140
	IRK72803	52.36339	104.25925	30.6 +/- 2.6	nd	nd	nd	nd
	IRK81601	52.24722	104.29056	nd	nd	nd	26.0 +/- 4.7	660 +/- 290
Angarsk - technical canal	AN72905A	52.50478	103.93449	nd	nd	nd	nd	nd
Angarsk - upstream								
Angarsk - passing the city	ANG73003	52.50669	103.96363	24.5 +/- 2.8	nd	nd	nd	nd
Angarsk - downstream								
Angara - before the junction	KUL80503	58.14652	93.58801	2.2 +/- 0.9	nd	nd	nd	nd

Table 11.2. (cont.) Preliminary Results of Gamma-ray Analysis

				Weighted Average Isotopic Activity [Bq/kg]#				
General Area	*Sample*	*Lat.(N deg.)*	*Long.(E deg.)*	*137Cs*	*60Co*	*152Eu*	*235U*	*238U*
Yenisey - before the	YEN80701	57.75829	93.26824	65.4 +/- 3.7	40.6 +/- 3.7	9.3 +/- 3.6	nd	nd
junction	YEN80702	57.75803	93.26075	22.9 +/- 2.3	8.6 +/- 1.9	6.7 +/- 3.0	nd	nd
	YEN80704	57.78082	93.29126	nd	nd	nd	nd	nd
	YEN80705	57.78322	93.29894	14.4 +/- 1.5	nd	nd	nd	nd
	YEN80706	57.86512	93.23768	77.7 +/- 3.2	48.6 +/- 3.1	12.0 +/- 6.0	nd	nd
	YEN80707*	57.91635	93.19787	392 +/- 12	241 +/- 11	153 +/- 29	nd	nd
	YEN80801	58.01997	93.14856	203 +/- 5.4	30.1 +/- 3.0	42.3 +/- 9.4	nd	nd
At the Angara - Yenisey	STR80603	58.09724	92.99269	211 +/- 6.2	96.9 +/- 5.1	56.6 +/- 14	nd	nd
junction								
Yenisey - after the	STR80606	58.30259	92.43286	27.1 +/- 3.8	nd	nd	nd	nd
junction	STR80605	58.24949	92.52090	2.9 +/- 1.3	nd	nd	nd	nd
Bratsk - above the dam	BRA81404	56.14171	101.79566	nd	nd	nd	nd	nd
Bratsk - below the dam	DAM81503	56.33675	101.85541	6.1 +/- 1.5	nd	nd	nd	nd
# errors given are two standard deviations								
** possible indications of 22Na and 65Zn*								
nd: not detected								

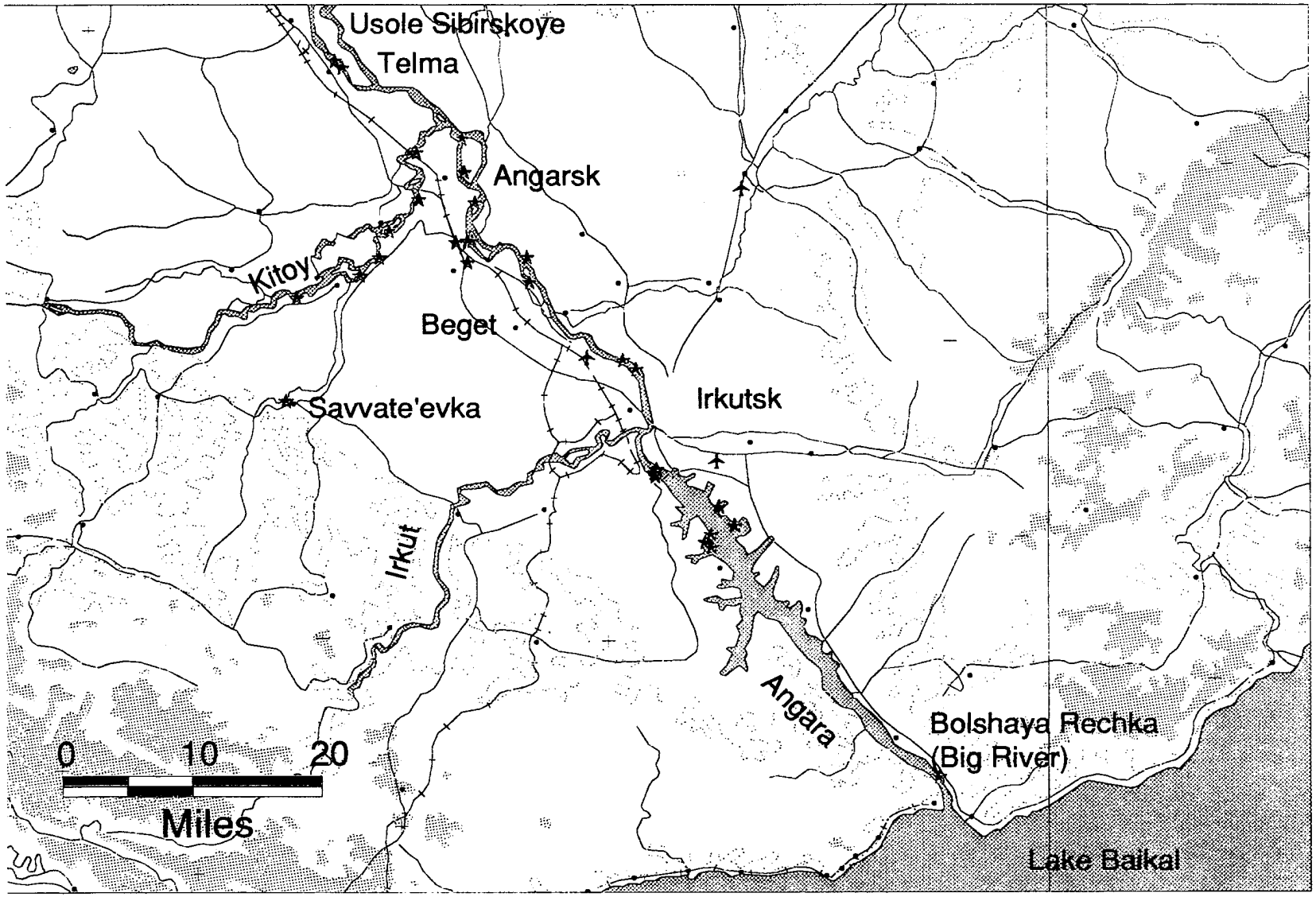

Figure 11.1. Map of the Irkutsk/Angarsk region. The stars indicate the sampling locations.

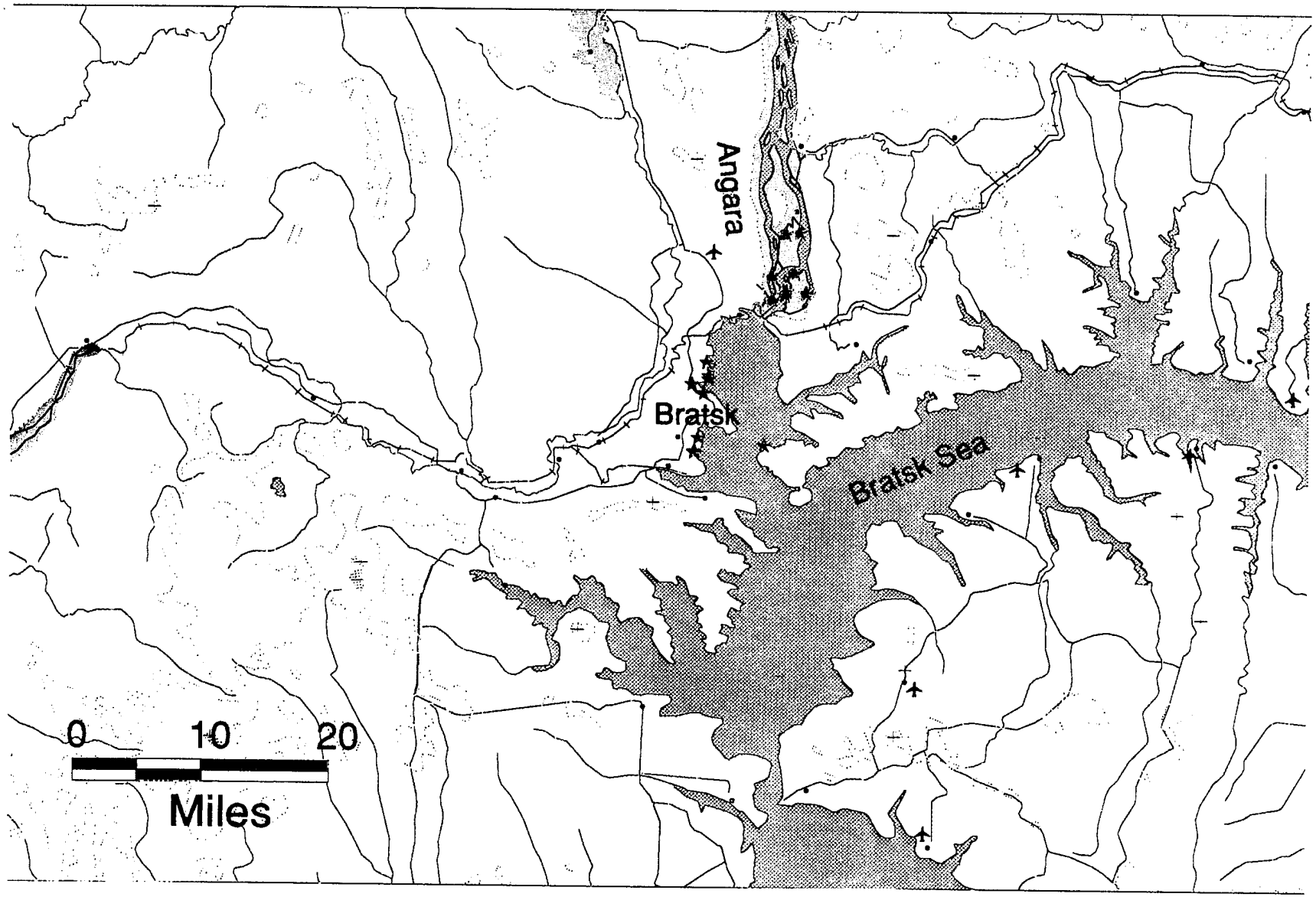

Figure 11.2. Map of the Bratsk region. The stars indicate the sampling locations.

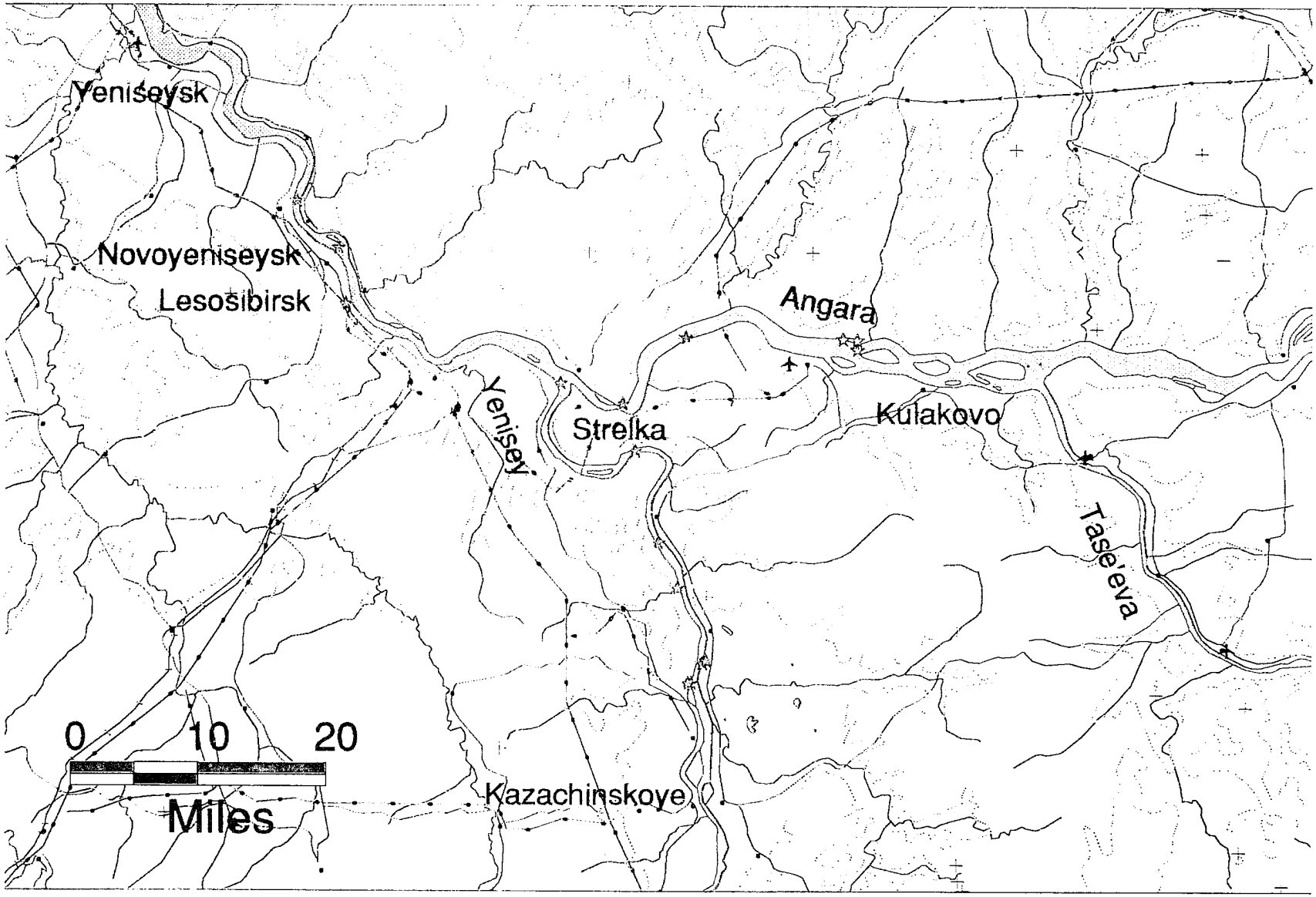

Figure 11.3. Map of the Angara/Yenisey junction region. The stars indicate the sampling locations.

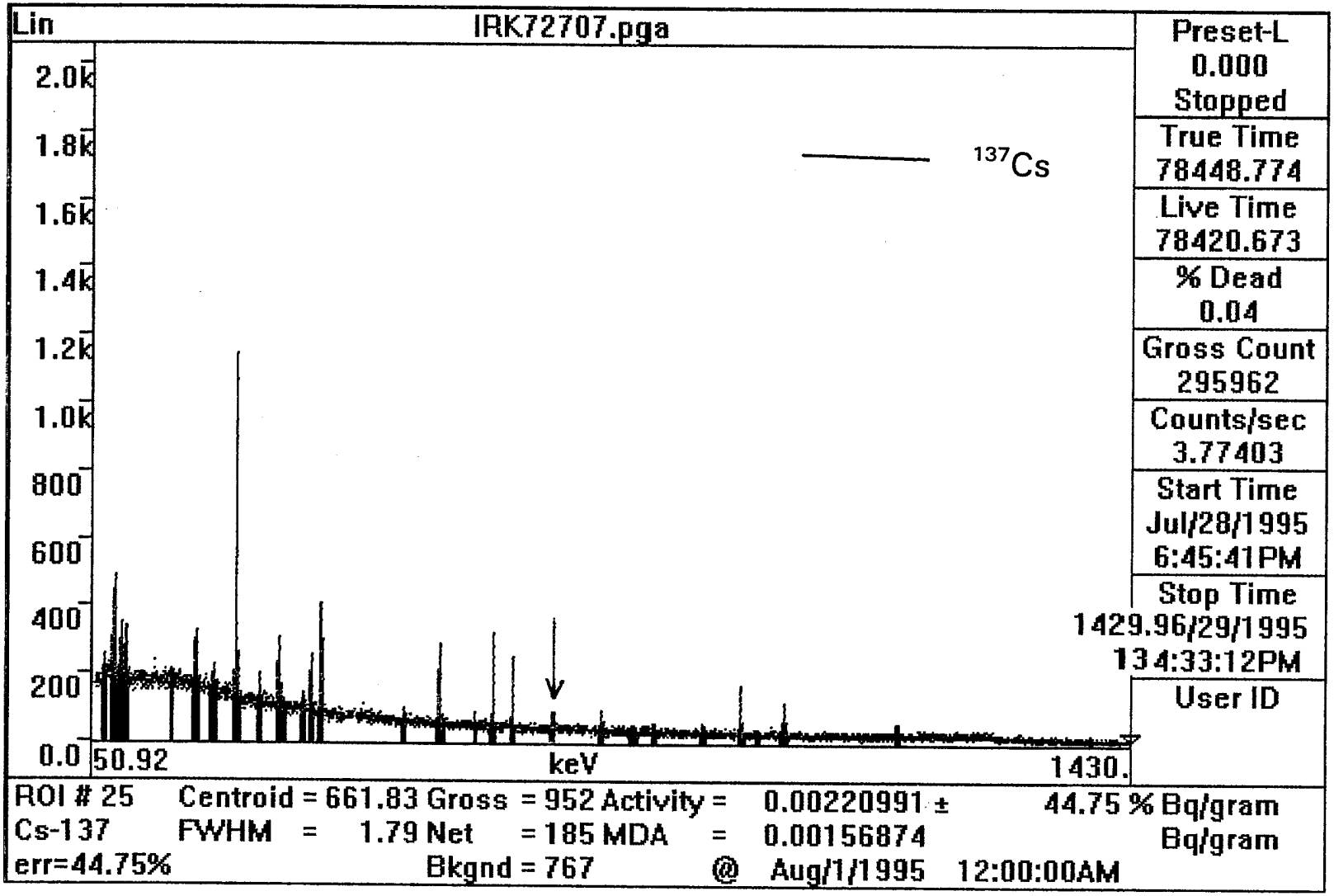

Figure 11.4. Gamma-ray spectrum of core sample from the Irkutsk reservoir on the Angara river upstream of the dam at Irkutsk. This spectrum is consistent with natural radioactivity plus the worldwide background of ^{137}Cs due to fallout.

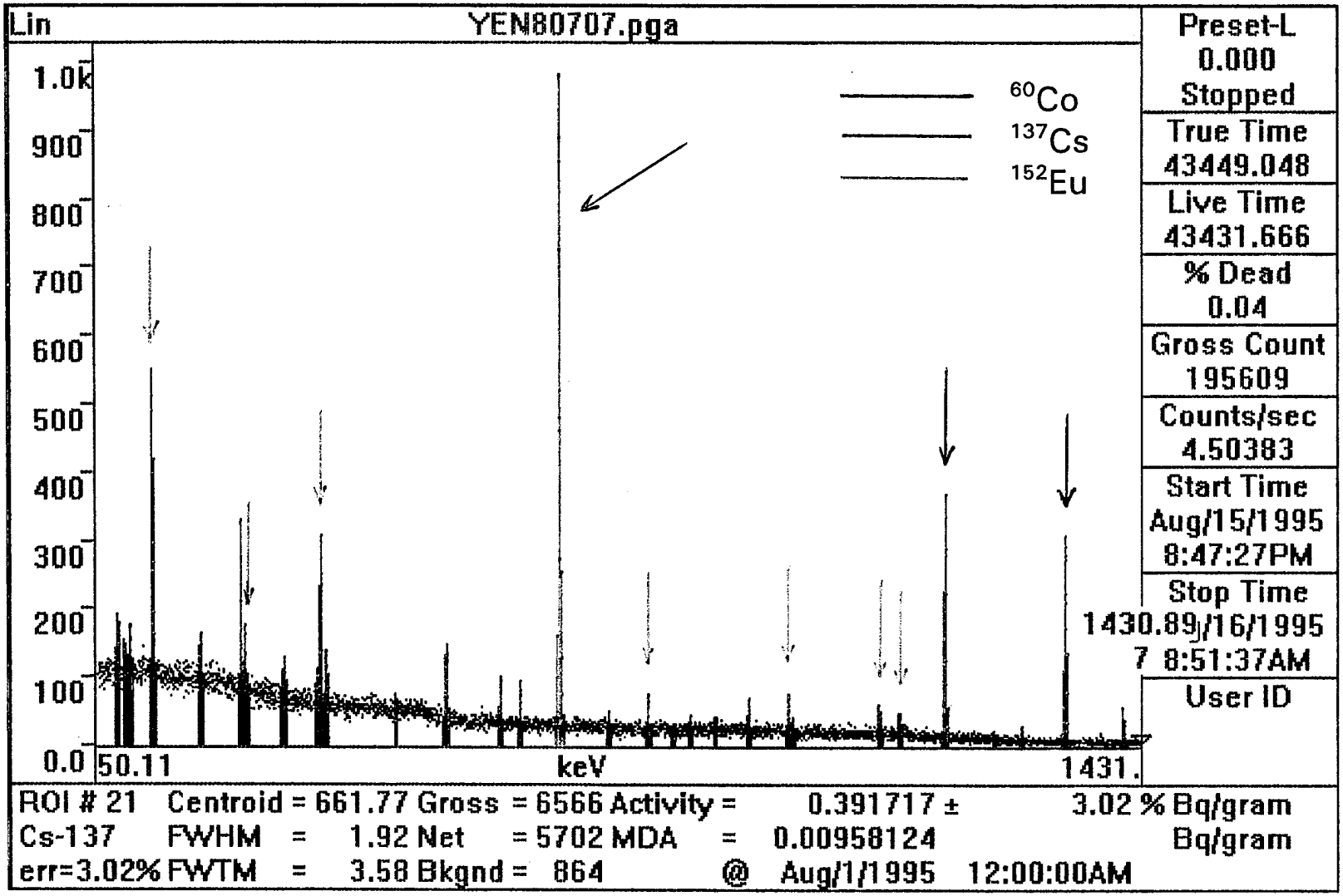

Figure 11.5. Gamma-ray spectrum of core sample from the Angara river below the dam at Irkutsk. This spectrum shows gamma-rays indicating the presence of natural uranium.

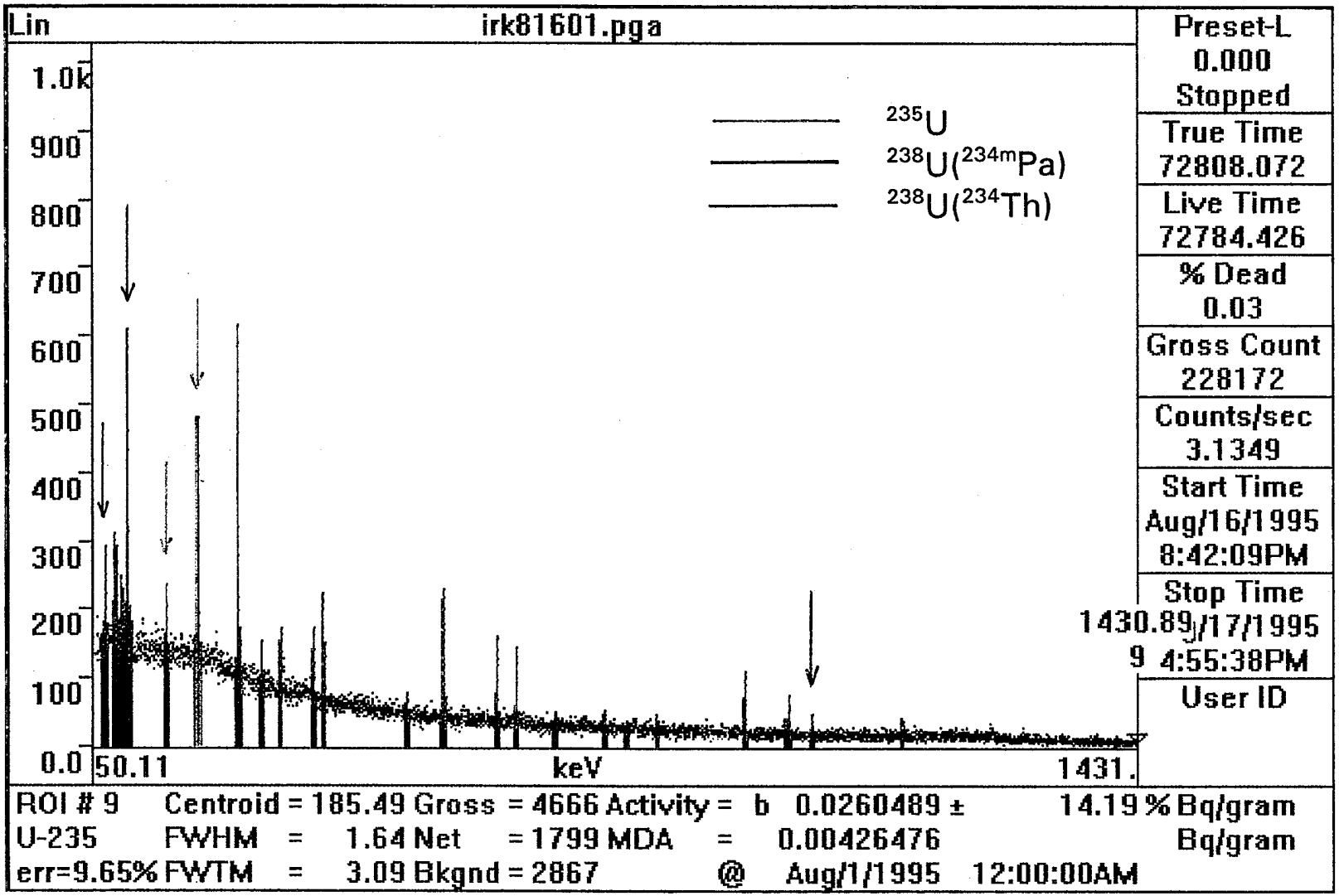

Figure 11.6. Gamma-ray spectrum of a core sample from the Yenisey river upstream from the junction with the Angara. This spectrum shows gamma-rays from reactor products and neutron activation products indicating material released from a reactor, most likely from the production reactors upstream at Krasnoyarsk.